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AN ANALYSIS OF A RAY TRACE EXPERIMENT ON THE UNDERWATER RANGE AT DABOB BAY

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THESIS

AN ANALYSIS OF A RAY TRACE EXPERIMENT
ON
THE UNDERWATER RANGE AT DABOB BAY

by

Victor Joseph Bankston

March 1975

Thesis Advisor: James V. Sanders

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20. results showed that the precision of the range position as determined by the ranging system is dependent only on the rise-time of the 75kHz signal; that the use of less environmental data and historical data as the environmental input for position calculations have been shown to cause only a minor degradation in the accuracy of the ranging system.

An Analysis of a Ray Trace Experiment
on
The Underwater Range at Dabob Bay

by

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Lieutenant, United States Navy
B.S., Louisiana State University, 1968

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY

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I. INTRODUCTION

An acoustic experiment was conducted to provide a basis for the comparison of various ray-tracing techniques which can be utilized to determine the three-dimensional position of a source with respect to a fixed receiver. The experiment was conducted at the Dabob Bay facility of the Naval Torpedo Station (NAVTORPSTA), Keyport, Washington on 21 March 1974 by members of the Ray Trace Committee of the Range Study Group at the Naval Postgraduate School, Monterey, California.

The purpose of the experiment was to determine what factors, both instrumental and environmental, influence range accuracy and precision. A preliminary investigation of two of the fifty-seven sets of data collected [Ref. 1] led to these tentative conclusions:

(1) The precision of the position location is essentially independent of the range from the array and depends only on the rise-time of the 75-kHz signal.

(2) There is no significant difference in the accuracy of results obtained by either isovelocity or isogradient ray-tracing techniques.

(3) The isogradient method appeared to need less environmental data to obtain a given precision.

This thesis was undertaken to verify and to extend the results of this preliminary investigation by testing the isogradient method of ray-tracing at all stations and depths studied and by determining the amount of environmental data required to maintain accuracy and by ascertaining if historical data rather than real time data may be utilized.

II. DABOB BAY TRACKING RANGE

A. DABOB BAY FACILITY

A facility for the three-dimensional tracking of surface ships, submarines, and torpedoes is located at the Dabob Bay facility of the Naval Torpedo Station, Keyport, Washington. Chosen because of its favorable oceanographic features and its proximity to the NAVTORPSTA, Keyport, Dabob Bay has been used for torpedo testing since 1949. It consists of a 75-kHz primary tracking system enveloping nearly the entire bay providing for underwater tracking in a volume approximately 30,000 feet by 4,500 feet by 600 feet deep.

Dabob Bay, a branch of the Hood Canal, is in a deep depression adjacent to the Olympic Mountains. The Quilcene River flows into the northernmost part and the Dosewallips River into the southernmost. The sides of the bay are precipitous and predominately rocky, while the bottom is mud. Annual precipitation averages about 15 inches and the average snowfall is about 15 inches. Winds generally blow along the length of Dabob Bay in a North-South direction. Normal wind velocities are 5 to 15 miles per hour. Tidal levels in Dabob Bay range from about -5 to +15 feet referenced to mean low-low water (MLLW).

Water temperatures change markedly from season to season and even from day to day. Salinity varies considerably with depth as fresher surface water from terrestrial runoff overlies more saline water. The variation in salinity is also quite seasonal, reaching a maximum in the spring. The main contributor to sound velocity changes is water temperature variation and the resulting sound velocity profile is representative of the temperature gradient.

B. RANGE DESCRIPTION

The basic underwater tracking system is comprised of three components: hydrophone array, computer system, and vehicular instrumentation. The shipboard transducer emits a 75-kHz acoustic pulse in synchronism with a master clock at the computer site. This pulse is detected by each of the four hydrophones in the array and mixed with a local oscillator having a frequency unique to that hydrophone.

The outputs of these oscillators are preamplified and fed to a multiplexer, which sums the signals and transmits the composite signal via underwater cable to the computer site, where it is processed to determine the in-water transit time to each hydrophone (Tx, Ty, Tz, Tc).

1. Hydrophone Array Configuration

The hydrophones in the NAVTORPSTA Range are arranged in a short-base line system in groups of four, each one located on one of four adjacent corners in an imaginary 30-foot cube, thereby defining the orthogonal coordinate system in which the measurements were made. These hydrophone arrays use buoyant spheres which exert an upward force in excess of two thousand pounds to keep them upright. The array is not free to rotate about the Z-axis, but may tilt as much as two degrees from the horizontal in strong currents. This tilt is measured by servo-pendulum transducers whose specified resolution is 0.00833 degrees, accuracy 0.025 degrees, and linearity 0.05 per cent over the full scale.

The range consists of six arrays (Fig. 1) aligned along a line 450 feet east and parallel to the range axis, spaced at 6000-foot intervals, with the 00 array being the farthest north. The range axis is 191° 18' 14" T.

2. Computer System

The computer system, a Scientific Data Systems (SDS) Model 920, is installed on Zelatched Point and consists of three main subsystems: the signal-processing subsystem, the data-collection subsystem, and the computer subsystem. The signal-processing subsystem, the link between the hydrophones and the data-collection subsystem, processes the multiplexed signal received from the arrays, discriminates against unwanted signals, and determines the in-water transit time to each hydrophone. The data-collection subsystem establishes the master clock timing by which all timing is computed. It also prepares all the array signals for the computer subsystem, which calculates the position of the tracked object, prints the tracking data, and records the data on magnetic tape. For the real-time examination, the data were plotted on X-Y plotters.

III. EXPERIMENTAL PROCEDURE

A 92.5-dB (re 1 μbar) acoustic source with approximately ten pounds of ballast was suspended from the stern of a sound boat to depths of 25, 50, 75, 100, 150, and 200 feet at six horizontal ranges (stations) from 900 feet to 4700 feet from the 02 hydrophone (Fig. 2). The first station was located approximately 900 feet north of the array, and 250 feet east of the range axis. Successive stations were located parallel to the range axis; the second being directly over the array, the third 600 feet past it, and then at about 1500-foot intervals to about 4500 feet, beyond which signal-to-noise problems made further examination impossible. The source emitted one 1.3 millisecond 75 kHz pulse per second for sixty to ninety seconds at each depth at each station.

The horizontal position of the boat on the range was found from the range's Autotape system, a portable commercial microwave system used exclusively for ship tracking that yields accuracies of ± 3 feet. The position of the acoustic source with respect to the Autotape antenna was determined from the length of cable let out, the horizontal distance from the antenna to the stern of the boat, and the ship's heading. Tidal data were recorded and used for correcting depth coordinates to MLLW. The array is known to be 585 feet below MLLW, so that the depth of the source below the surface and the tide measurement allows calculation of the vertical distance between the source and the array. All measurements were made with respect to the array's coordinate system, although the array's orientation and location on the range were known, making it possible to transform this data to a true position on the range. The X-axis of the 02 array was 25° 24' 36.0" T.

A NAVTORPSTA digital velocimeter that has an accuracy to ±1.0 ft/sec and resolution of ± 0.7 ft/sec was used to measure the sound-velocity profile at each station. NAVTORPSTA instrumentation at Dabob Bay measured and recorded the acoustic travel times from the source to each of the four hydrophones in the array to six decimal places for every source depth at each station. The three-dimensional position of the source with respect to the array was calculated by the NAVTORPSTA NUTRAK III computer program.

The data were gathered on 21 March 1974 during a neap tidal period and while the bay surface was smooth and glassy, although there had been ripples earlier in the day. The day was bright and sunny with scattered, thin, high overcast, the temperature was 55°F, and no noticeable wind was present. The shiny stainless steel transducer disappeared from view when about eight feet deep, indicative of thick biological concentrations in the water. Rudimentary drift measurements of boat movement relative to the surface water were taken by throwing paper into the water and watching its relative motion with respect to the boat, which indicated a value of approximately 0.3 ft/sec.

IV. RANGE DETERMINATION TECHNIQUES

A. TECHNIQUES

The three-dimensional position of an acoustic source with respect to a receiver may be readily determined by computer analysis. Two ray-tracing techniques which are easily adaptable for high-speed digital computation are: (1) an isovelocity technique in which the water mass is divided into layers of isovelocity water; and, (2) an isogradient technique in which the water is divided into isogradient layers. Both techniques utilize Snell's law, which describes the refraction of sound rays in a medium of variable velocity.

The isovelocity method is currently utilized in the NAVTORPSTA procedure NUTRAK III. STUTRACK I was developed in the preliminary experimental analysis. It consists of both an isovelocity and an isogradient method to be utilized as comparators with NUTRAK III. Both programs require as inputs the velocity profile, the transit time and angle of arrival of the acoustic wave at the geometrical center of the array.

B. PREPARATION OF DATA

The required inputs for the computer analysis must be derived from the information available at the array, which is the transit times of the acoustic pulse from the tracked source to the four hydrophones of the receiving array. The geometry involved in the calculation of the raw array coordinates is shown in Figure 3. The expressions for the raw array coordinates are:

$$\mathrm{RAWX} = \frac{c^2}{2d} \quad (T_c + T_x) \quad (T_c - T_x) \tag{1}$$

$$\mathrm{RAWY} = \frac{c^2}{2d} \quad (T_c + T_y) \quad (T_c - T_y) \tag{2}$$

and

$$\mathrm{RAWZ} = \frac{c^2}{2d} \quad (T_c + T_z) \quad (T_c - T_z) \tag{3}$$

where

c = the average sound velocity, ft/sec;

d = the distance between hydrophones, 30 ft;

T_x, T_y, T_z, T_c = travel times to respective hydrophones, sec.

A correction factor must be applied to correct for the array receiver integration time (pulse width discrimination), 800 μs. The relations now become:

$$\mathrm{RAWX} = \frac{c^2}{2d} \quad (T'_c + T'_x - K) \quad (T'_c - T'_x) \tag{4}$$

$$\mathrm{RAWY} = \frac{C^2}{2d} \quad (T'_c + T'_y - K) \quad (T'_c - T'_y) \tag{5}$$

and

$$\mathrm{RAWZ} = \frac{c^2}{2d} \quad (T'_c + T'_z - K) \quad (T'_c - T'_z) \tag{6}$$

where

K = twice the integration time, 1.6×10^{-3} s.

T'_x, T'_y, T'_z, T'_c = the measured transit time, sec.

These raw coordinates are referenced to a non-horizontal reference plane due to the array's freedom to tilt in the horizontal. The array is instrumented to sense the angles the array axis makes with the horizontal, XTILT and YTILT.

The correction of the RAW coordinates is a matter of geometry, as shown in Figure 4. The corrected coordinates become:

$$\mathrm{CORX} = \mathrm{RAWX} - \mathrm{RAWZ}\ [\mathrm{SIN}(\mathrm{XTILT})] \tag{7}$$

$$\mathrm{CORY} = \mathrm{RAWY} - \mathrm{RAWZ}\ [\mathrm{SIN}(\mathrm{YTILT})] \tag{8}$$

$$\mathrm{CORZ} = \mathrm{RAWZ} + \mathrm{RAWX}\ [\mathrm{SIN}(\mathrm{XTILT})] + \mathrm{RAWY}\ [\mathrm{SIN}(\mathrm{YTILT})] \tag{9}$$

In a homogeneous body of water, the minimum time path between an output transducer and a receiving hydrophone is a straight line. When the speed of propagation is spatially varying due to temperature and salinity variations, refraction occurs and the minimum time path is no longer a straight line (Figure 5). Corrections must therefore be made to determine the true position of the source.

From Snell's law, a minimum time path is computed, working back in time from the array center in the direction of the "apparent" position and tracing the acoustic ray through each velocity layer until the measured time is consumed. The vertical angle of entry at the array, computed from the tilt-corrected array coordinates is

$$A_o = \mathrm{SIN}^{-1} \left[\frac{\mathrm{CORZ}^2}{\mathrm{CORX}^2 + \mathrm{CORY}^2 + \mathrm{CORZ}^2} \right]^{1/2} \tag{10}$$

This entry angle is assumed to be equal to the entry angle for the minimum time path. This assumption is good if the source is far enough so that the wave fronts are planar over the dimensions of the array, and the speed of sound is constant over the dimensions of the array.

The travel time, T, to the origin is computed from

$$\frac{T}{T_c} = \frac{S}{R_c} \tag{11}$$

where

$$S = [(\mathrm{CORX})^2 + (\mathrm{CORY})^2 + (\mathrm{CORZ})^2]^{1/2} \tag{12}$$

and

$$R_c = [(CORX + 15)^2 + (CORY + 15)^2 + (CORZ + 15)^2]^{1/2} \tag{13}$$

where R_c is the slant range to the array center hydrophone, and S is the slant range to the array center.

The entry angle, A_o, the travel time, T, along with velocimeter data describing the sound velocity profile may now be utilized as inputs to the computer program. The outputs will provide the three-dimensional position of the source with respect to the receiver.

V. PRELIMINARY ANALYSIS

A. ANALYSIS

The analysis of the experimental data was to have determined the accuracy of NUTRAK III as compared with both modes of STUTRACK I. The Autotape system was to form the reference for this determination, but its precision was much less than expected. The analysis was, therefore, primarily devoted to the determination of the precision of the various methods of ray-tracing. Stations 1-25 and 6-50 were chosen for preliminary investigation since station 1 was closest to the array and station 6 was farthest. The effects of varying the amount of environmental data was also investigated.

B. RESULTS

NUTRAK III showed good point to point continuity at station 1 for all coordinates, while the coordinates at station 6 were very erratic. A transformation of the coordinates to a spherical coordinate system showed that the variations of phi versus theta to be approximately the same at both stations.

Both modes of STUTRACK I were compared to NUTRAK III and in both cases no significant differences were noted when the most structured sound velocity profile was utilized. As the number of linear segments defining the sound velocity profile was decreased, the isovelocity technique provided consistently poorer results. Using the isogradient technique to compute the source's position resulted in only a slight degradation as the number of segments in the profile was decreased and was considered adequate in precision.

C. CONCLUSIONS

Comparison of the two stations investigated showed station 6-50 to have greater spatial variability. The transformation to spherical coordinates shows the difference is not present in the angular display as would be expected if the time errors were the important source of variability. Improved range accuracy can only be obtained by improving the accuracy of the time measurements or increasing the baseline of the hydrophone array. The isogradient method of STUTRACK I provides greater precision than the two isovelocity techniques when less environmental data was utilized.

VI. PRECISION OF DATA

The data collected at Dabob Bay were tested at all stations to verify that the results of the preliminary analysis were generally applicable. If the precision was independent of range and depth the standard deviation of the source coordinates as calculated from the transit times at the array should be zero with a small standard deviation about the mean. Factors which could cause variation are the rise-time of the 75-kHz source (as discussed in the preliminary analysis), and the actual drift of the source transducer caused by the currents which exist in the experimental area.

Analysis of the precision of the ranging system must remove the effects of drift from the calculations. Regression analysis on the components of the calculated horizontal position of the source provided an equation for the displacement of the transducer as a function of time. A second-order regression equation was considered to adequately describe this displacement as it accounts for the velocity and acceleration components of the drift.

Each set of data was processed to determine the calculated components of the source position. Each horizontal component was fitted to a simple second-order curvilinear regression equation with time being the independent variable and the corresponding component as the dependent variable. The value of the component evaluated from the regression equation for each time was taken as the estimated value at that time. By taking the difference between the estimated and the corresponding calculated values the effects of drift are removed from the computations. The mean depth was taken to be the simple arithmetic mean. The standard deviation, standard

error of estimation, of these differences between the estimated and calculated coordinates is a measure of the precision of the ranging system. Tables I-III show the standard errors for the theta, phi, and radius components of the source position for all stations and depths. Figures 6 and 7 are scatter diagrams of the standard errors of phi versus theta by station in Figure 6 and by depth in Figure 7. Both Figures show that the standard errors with the drift effects removed are essentially random with no dependence on station or depth.

VII. ENVIRONMENTAL EFFECTS ON RANGE PRECISION

The effect on range position accuracy and precision due to varying the amount of environmental information was investigated by varying the number of linear segments which were used to describe the sound velocity profile. Decreasing the number of segments which describe a particular profile while maintaining the required precision would result in faster processing time for the ranging data.

Three methods of decreasing the number of segments in a profile were studied: (1) equal changes in gradient; (2) equal changes in velocity; and (3) "eyeball" fitting. All three methods were compared to determine which would suffer the least degradation in accuracy and precision as the profile was simplified. In the experiment, environmental data was provided by a velocimeter which described the existing sound velocity profile in 64 to 67 discrete points in 600 feet. Any profile described adequately with fewer points would significantly reduce data processing time. The equal-change-in-gradient and velocity methods utilized in this investigation were developed by the author for this analysis.

The equal-change-in-gradient method determines a set of linear segments by locating the depth and velocity points which, if connected by straight lines, would cause a given percentage change in the gradient. The first three points from the bottom of the most detailed sound velocity profile are fitted with a straight line by the method of least squares. The slope of this line is used as the initial reference gradient. The gradient of the linear segment in the original profile between the first point used to determine the reference gradient and the next point

in the profile is computed. This gradient is compared with a test value given by the reference gradient plus a designated change from 5 to 30%.

When the computed gradient exceeds the test value, the prior point in the profile is considered as the end point in that segment. The points thereby included in this segment are fitted by the method of least squares. The end point of the segment which has been processed is now the first point used in the determination of a new reference gradient as described above and the next linear segment is determined by repeating the process. The velocity at the highest depth of the initial segment does not equal the velocity at the lowest point of the second segment after processing; therefore, an adjustment must be made to cause the two segments to intercept at this mutual depth. This adjustment consists of making the sound velocity of both profiles the mid-point of the calculated velocities at that depth. This process is continued until the surface is reached. Appendix A is a listing of the computed program which utilizes this method for decreasing the number of segments which describes a sound velocity profile.

The equal-change-in-velocity method utilizes a constant percentage change in velocity between the minimum and maximum velocities in the profile and the minimum and maximum velocities to decrease the number of segments in the profile. The minimum and maximum sound velocities of the original profile are located; a fixed percentage (5 to 30%) of the difference between them is used to determine the velocity at each point in the new profile. The surface sound velocity is incremented by the given change in velocity and the original profile is searched until the depth of the incremented velocity is located or the minimum or maximum velocities occur. The method determines the direction of the change in

velocity from the original profile. Once the new point in the profile is determined, its velocity is incremented and the sequence, as described above, continues until the bottom of the original profile is reached. The original sound velocity profile is now described by a lesser number of linear segments. Appendix B is a listing of the computer program which utilizes this method.

The "eyeball" method is simply the author's estimate of the best-fitted segments which describe a sound velocity profile. It is derived by estimating the segments which provide the best description of the original profile in the minimum number of segments. Then by decreasing the number of possible segments, estimates are made of the best-fitted profile with the decreased number of segments.

Thirteen curves describing the sound velocity profiles at both stations 1 and 6 were determined using the above methods, six by the equal-change-in-velocity method, three by the equal-change-in-gradient method, and four by the "eyeball" method. Figures 8-10 show the change in the characteristics of the profile at station 1 due to its description by each of these methods. These profiles were used to study the effect on source position due to varying the amount of environmental data. The position of the source at each depth for stations 1 and 6 was calculated for each profile. Tables IV-VII show the resultant standard errors of estimate from these calculations. At both stations the standard error of the theta and phi components remained constant as the amount of environmental data was varied. The standard error of the slant range changed with each profile. Excluding the results for the "eyeball" method at station 6, the average standard error for all methods was 0.181 feet at station 1 and 0.317 feet at station 6. The average standard errors by

method for stations 1 and 6 were: (1) equal-change-in-velocity, 0.160 and 0.343 feet; (2) equal-change-in-gradient, 0.220 and 0.318 feet; and (3) "eyeball", 0.172 and 1.586 feet. The equal-change-in-velocity method appears to cause the least degradation in positional precision with the least environmental data at these two stations.

VIII. HISTORICAL ENVIRONMENTAL ANALYSIS

The possibility of using historical environmental information rather than real-time information as the sound velocity input for computing position has as its major advantage the lessening of the cost and time required prior to performing any range operation. Historical information along with its reduction by the methods discussed in Chapter VII would decrease total processing time and, thereby, increase the efficiency of the ranging system. This hypothesis is only valid if the use of this information does not degrade the accuracy of the positional calculations. The objective of this section, therefore, is to analyze the feasibility of utilizing historical environmental information in computing position with precision as the measure of effectiveness.

Figures 11 thru 22 show the twelve sound velocity profiles which describe the environmental conditions which exist at Dabob Bay. The profiles were based on three years (1971-1973) of environmental information collected at the facility [Ref. 2]. Each profile type shows the minimum, maximum, and median (mid) profiles which are characteristic of the particular type. These historical sound velocity profiles were used in this analysis.

In order to perform the analysis, the inputs for the range positioning algorithm, STUTRACK I, had to be determined based on the historical profiles. A simulation was developed to generate the transit time of an acoustic pulse from a source to the array, the angle of entry of the acoustic wave with respect to the center of the array, and the apparent horizontal distance of the source from the array. The simulation

generates these parameters by searching for the entry angle in which a ray would enter the array from a known position of a source. Once the entry angle is located, the transit time for that angle is determined. This simulation, as with STUTRACK I, utilizes Snell's law as its basis and performs the same calculations as STUTRACK I, but in reverse order. Appendix C is the computer listing of the subroutine, ANGCAL, developed for the simulation.

The simulation computes the input data for STUTRACK I at a fixed horizontal position from the array. This position was chosen to provide a horizontal range from the array similar to that of station 6 in the experiment. Fifty vertical points at four-foot intervals from the surface to 200 feet were used as the vertical component of the source position. The use of this scenario was chosen to provide data for the analysis under the conditions that were found to cause the least precision of source position in the experiment, station 6.

Each of the historical profiles was first described in 60 ten-foot layers from the surface to 600 feet, and this description was used as the environmental input for the simulation. The transit time, entry angle, and apparent horizontal range for the 50 positions were used to compute the three-dimensional position of the source with STUTRACK I. Each historical profile was then reduced using the equal-change-in-velocity method at five to thirty percent change intervals, providing approximations to the original profile. Each of these simplified profiles was used as the environmental input to STUTRACK I and the source position was calculated with the transit times, entry angles, and horizontal ranges from the original profile.

The position of the source as calculated from the reduced profiles was compared to that of the original profile. The standard error of estimate for each of the reduced profiles was determined for the 36 profiles describing the twelve historical profiles at Dabob Bay. A comparison of the minimum and maximum profiles of a particular type with the mid profile was also performed. This comparison was designed to show the effects of using a single profile to describe the environment when the actual profile existing at that time is within the range of a particular sound velocity type. Table VIII shows the results of these comparisons for Profile Type Four. All profile types showed similar results.

In conducting the above comparisons, it was noticed that much larger errors occurred at shallower depths. Each profile type shows its greatest variation near the surface due to water runoff, solar insolation, and seasonal temperature variation. Therefore, it was decided to perform the same analysis as above, but with the data points below the point where large variations in the gradients of the minimum and maximum profiles of a sound velocity type occurred. The calculations were performed between 100 and 300 feet. Table IX shows the results of these calculations for Profile Type Four as before. The values, as calculated from data points between 100 and 300 feet, generally, showed less standard error than the values calculated using the same number of points between the surface and 200 feet. Table X shows this comparison.

IX. CONCLUSIONS

A. PRECISION OF DATA

The analysis of the experiment showed conclusively that although the magnitude of the spatial variation grows as the source's range from the array increases, the variation in the angular description of source position is independent of range. This is consistent with the results of the preliminary investigation. It is concluded that the increase in the spatial variation of the range position discrimination of the 2.5-MHz clock in measuring the arrival time of the 75-kHz source signal used in the experiment. This uncertainty can cause a maximum error of 3.3 μsec in the arrival time which is one-fourth of the period of the 75-kHz signal, causing an error of approximately one foot at station 1 and 4.5 feet at station 6.

B. ENVIRONMENTAL EFFECTS ON RANGE PRECISION

The investigation of precision of range position due to the amount of environmental information used in the calculations has shown that the method of describing the existing profile is not critical. Of the three methods of reducing the number of segments describing the existing sound velocity profile, the equal-change-in-velocity method appears to produce results with more precision than either the equal-change-in-gradient or "eyeball" fit methods. Describing a profile in terms of a 20 percent equal change in velocity between segments, usually six or seven segments, produces the best precision with the minimum amount of environmental information required for calculations. This result is independent of depth and horizontal range.

C. HISTORICAL ENVIRONMENTAL ANALYSIS

The analysis of the twelve profile types which describe the acoustic environment at Dabob Bay show that the use of historical information rather than real-time environmental data is indeed feasible. The use of a profile which has been reduced by a 20 percent change in velocity in the equal-change-in-velocity method provides the most precision for all velocity profile types studied. The use of the mid profile to describe any profile falling within the range of a particular type causes very little degradation in precision. Therefore, it is concluded that the use of historical data is feasible in the determination of the source position and only a small number of segments are required to describe the existing sound velocity profile.

X. COMMENTS AND RECOMMENDATIONS

This thesis has verified the preliminary conclusions reached in Reference 1, that the precision of the range position in calculations is a function of the rise-time of the 75-kHz acoustic signal used in the experiment. The angle of entry of the signal to the array is thus the critical factor in range precision. Increasing the accuracy of time measurement and decreasing the error due to rise-time (increasing the array baseline) will improve precision.

The historical profiles may be segmented as described in this thesis and catalogued. The sound velocity profile which actually exists on the range could be sampled daily with a velocimeter. This profile can then be fitted to an historical profile type which describes it and the appropriate catalogued sound velocity profile used as the environmental input for any range positioning calculations to be performed that day.

As noted in the preliminary investigation, the sum of the source depth and the individual calculated Z component at each time differed from the known array depth. The range of this difference was +4.8 to -18.8 feet with the average being 3.1 feet less than the array depth. Verification of the recorded tidal levels with the predicted tides at the time the experiment was conducted showed no discrepancies of this magnitude.

Further study should be conducted to determine the accuracy of the ranging system at Dabob Bay and Nanoose and to provide a greater confidence level in the use of less environmental data in range position calculations. The apparent inaccuracy in the Z component should receive special attention.

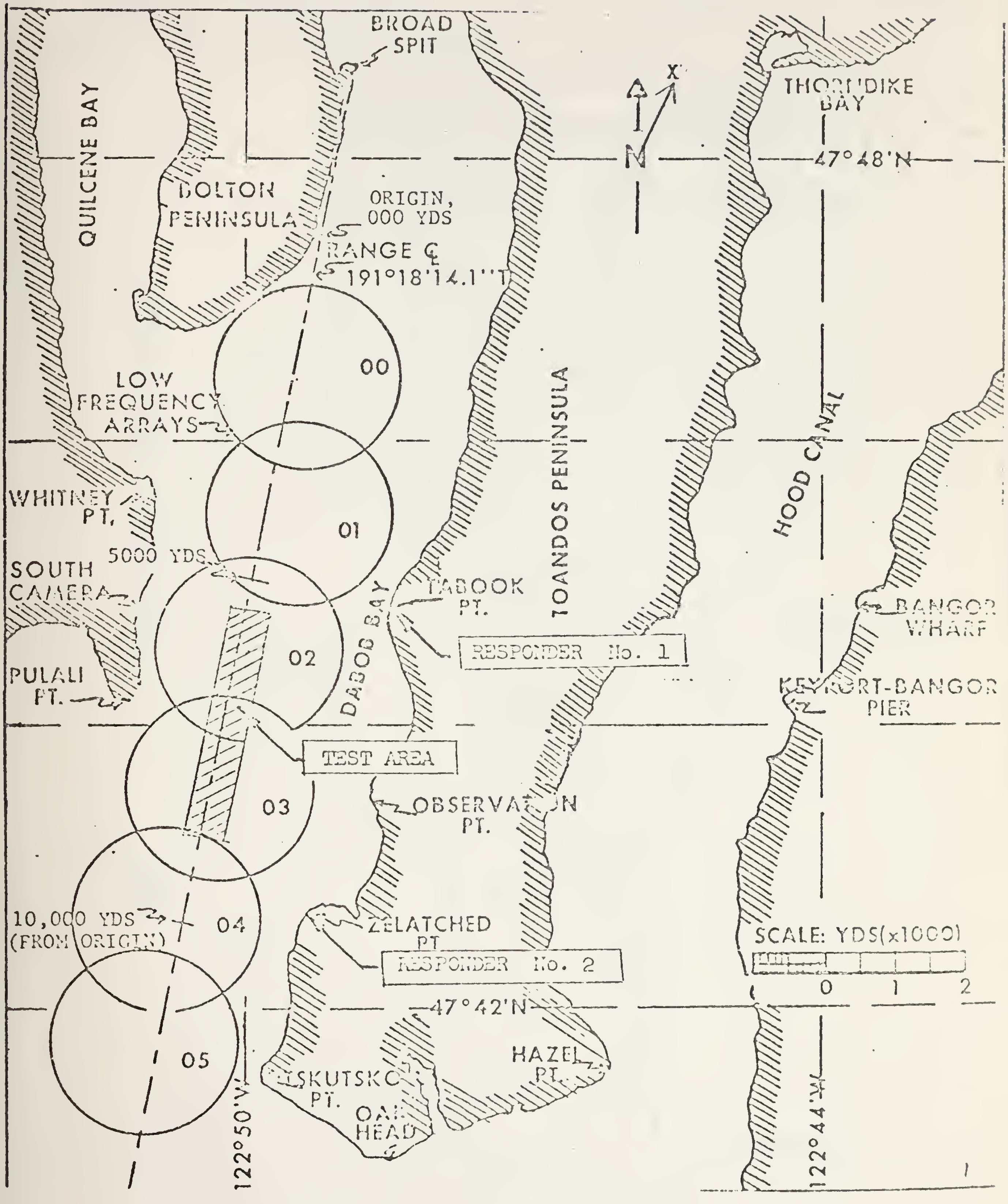
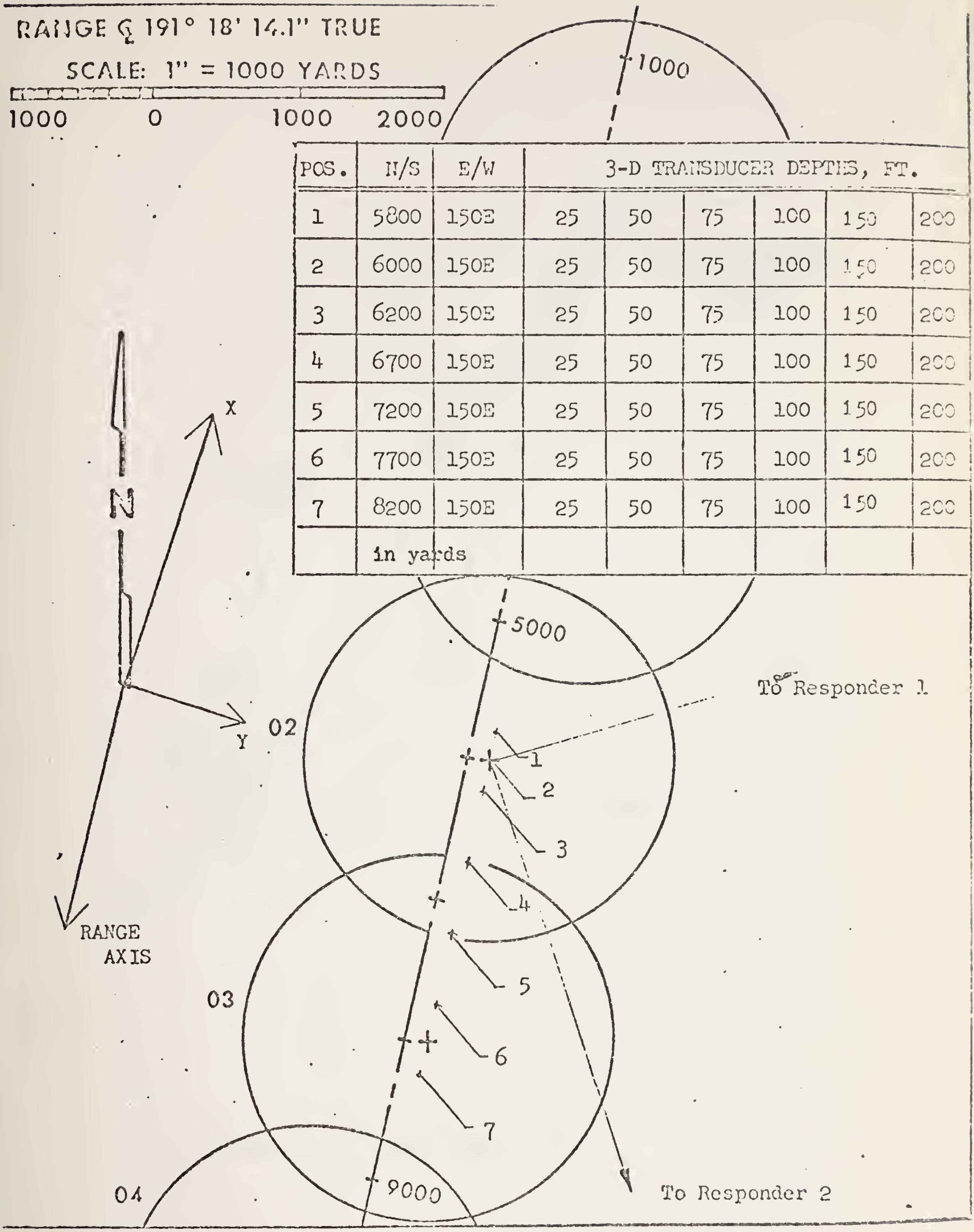


FIGURE 1. DABOB BAY RANGE



POS.	N/S	E/W	3-D TRANSDUCER DEPTHS, FT.					
1	5800	150E	25	50	75	100	150	200
2	6000	150E	25	50	75	100	150	200
3	6200	150E	25	50	75	100	150	200
4	6700	150E	25	50	75	100	150	200
5	7200	150E	25	50	75	100	150	200
6	7700	150E	25	50	75	100	150	200
7	8200	150E	25	50	75	100	150	200
	in yards							

FIGURE 2. EXPERIMENTAL AREA

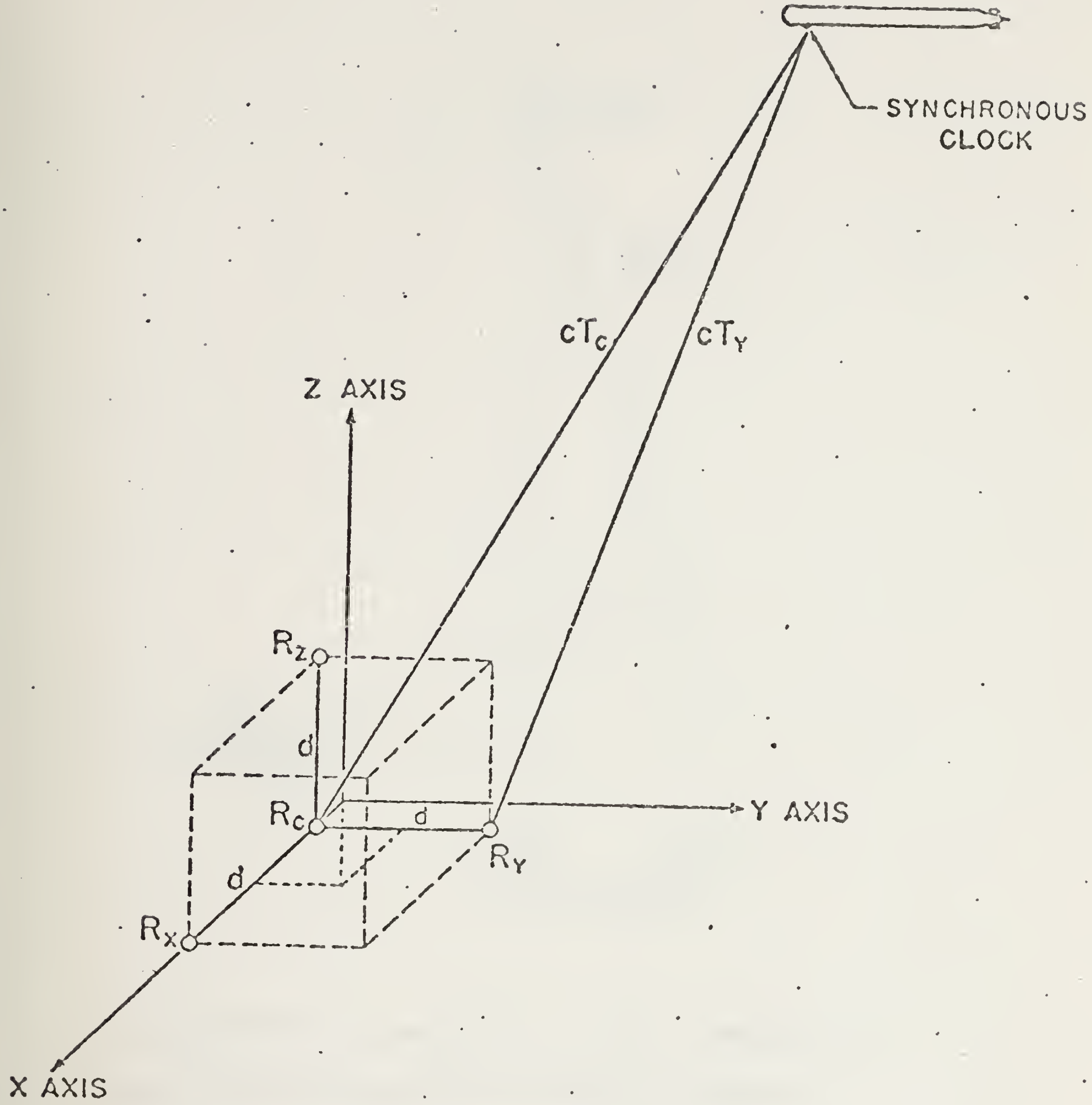
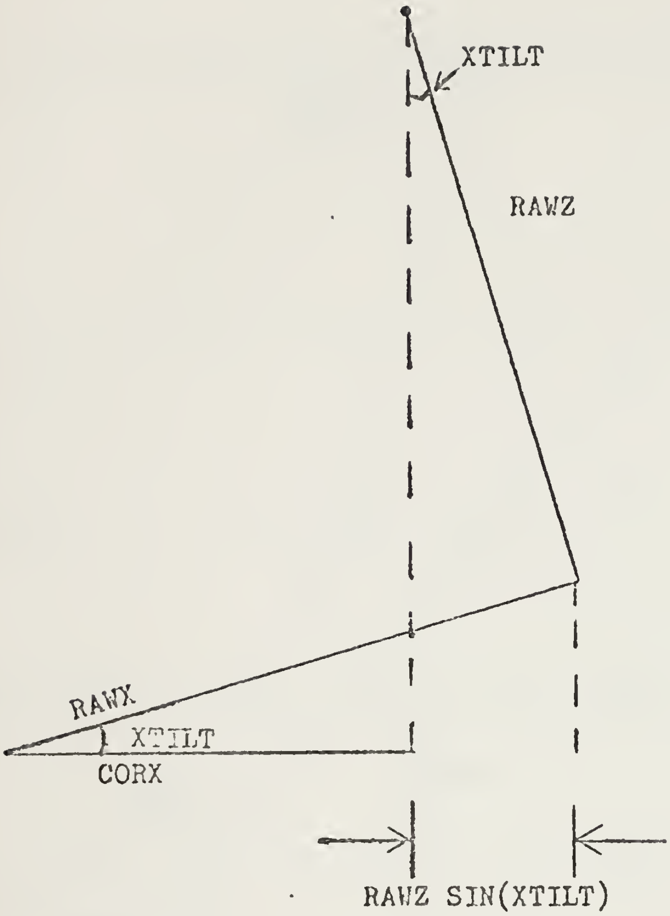


FIGURE 3. HYDROPHONE ARRAY



The SIN(XTILT) is positive when the X transducer is above the horizontal plane passing through the C transducer, and negative when the X transducer is below the horizontal plane passing through C.

FIGURE 4. TILT CORRECTION

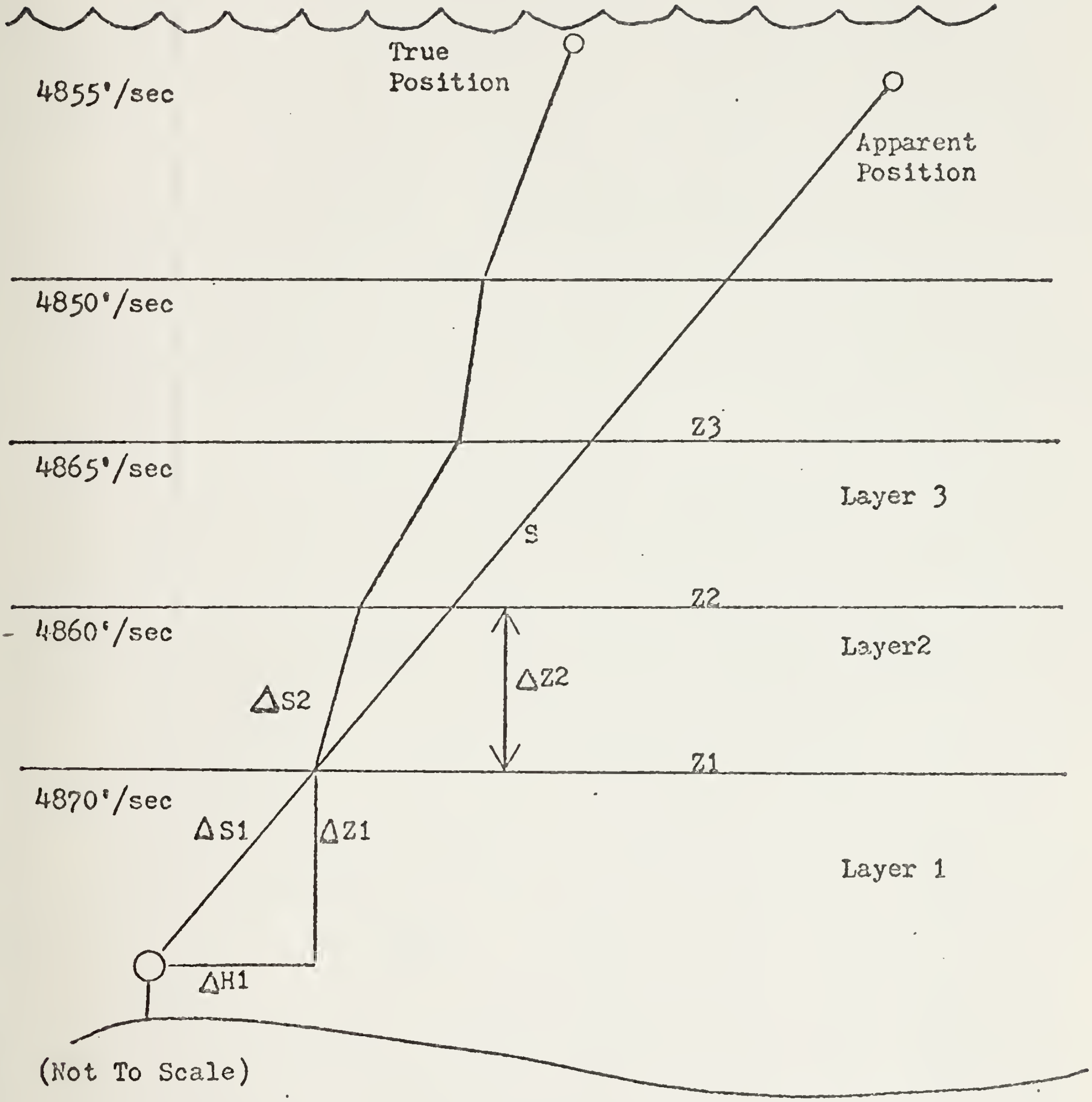


FIGURE 5. RAY PATH REFRACTION

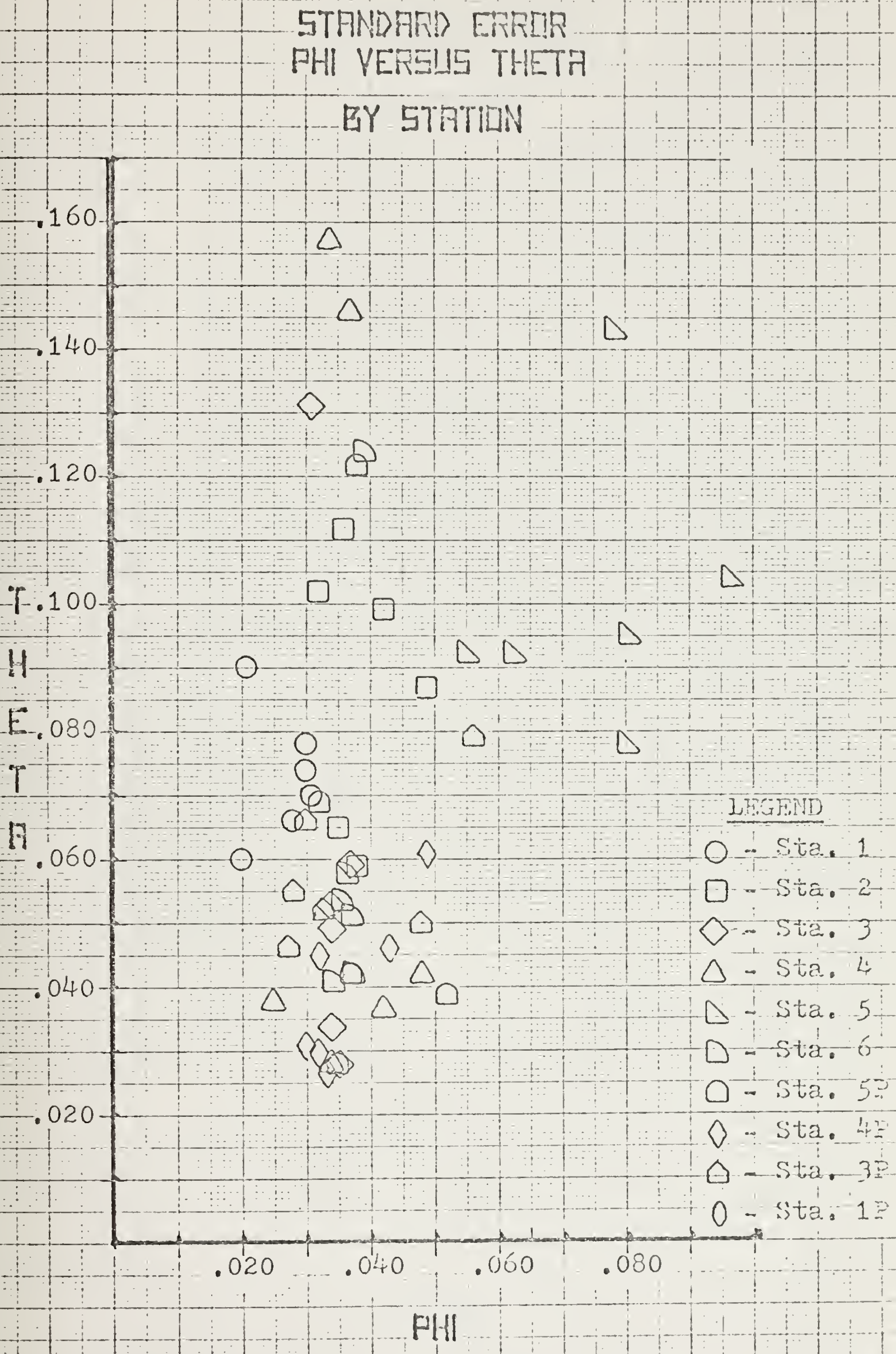

STANDARD ERROR
PHI VERSUS THETA
BY STATION
THETA
.160
.140
.120
.100
.080
.060
.040
.020
.020
.040
.060
.080
PHI
LEGEND
○ - Sta. 1
□ - Sta. 2
◇ - Sta. 3
△ - Sta. 4
◺ - Sta. 5
D - Sta. 6
⌓ - Sta. 5P
⬯ - Sta. 4P
⌂ - Sta. 3P
0 - Sta. 1P

FIGURE 6

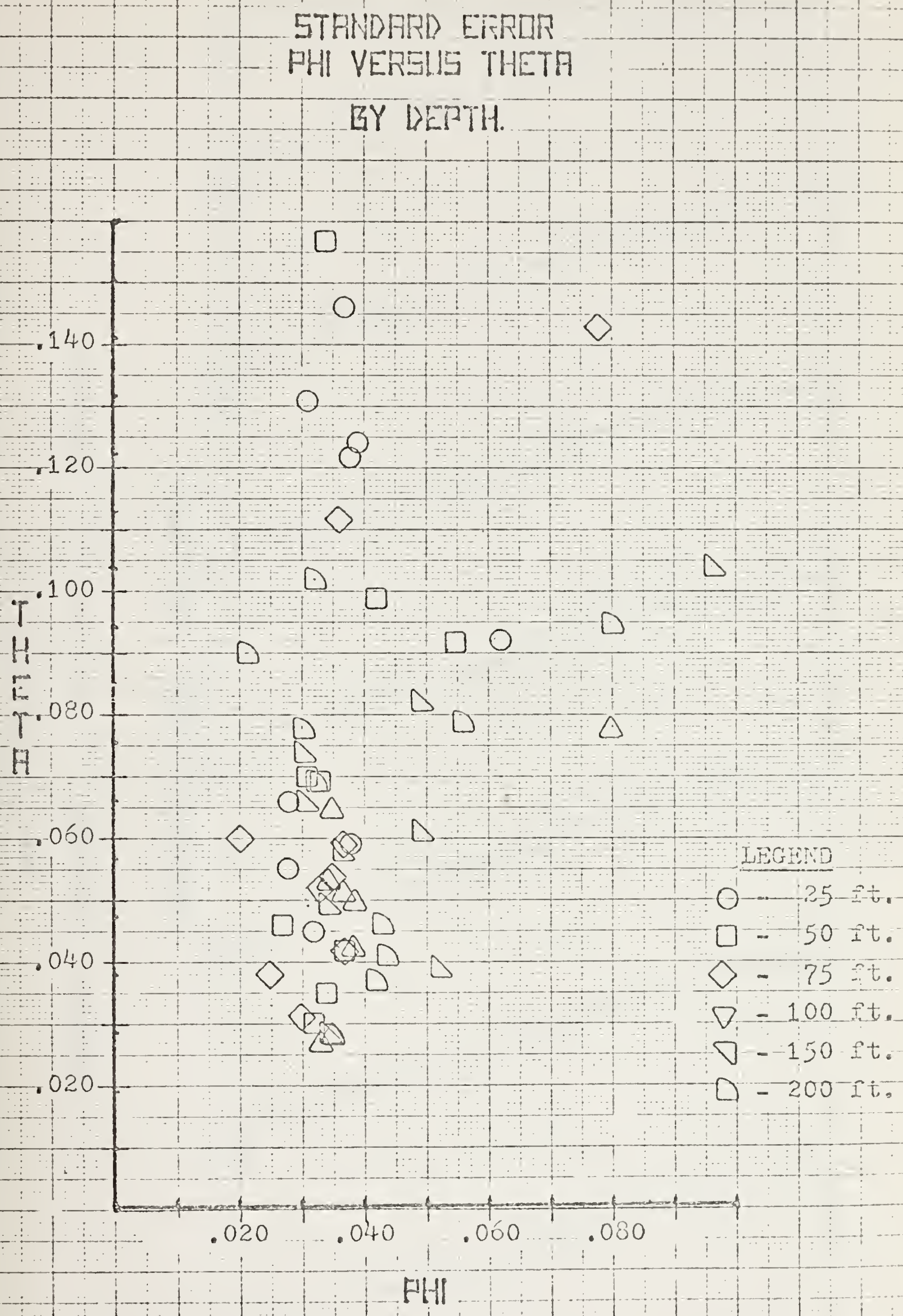

STANDARD ERROR
PHI VERSUS THETA
BY DEPTH.
THETA
.140
.120
.100
.080
.060
.040
.020
PHI
.020
.040
.060
.080
LEGEND
○ - 25 ft.
□ - 50 ft.
◇ - 75 ft.
▽ - 100 ft.
◁ - 150 ft.
D - 200 ft.

FIGURE 7

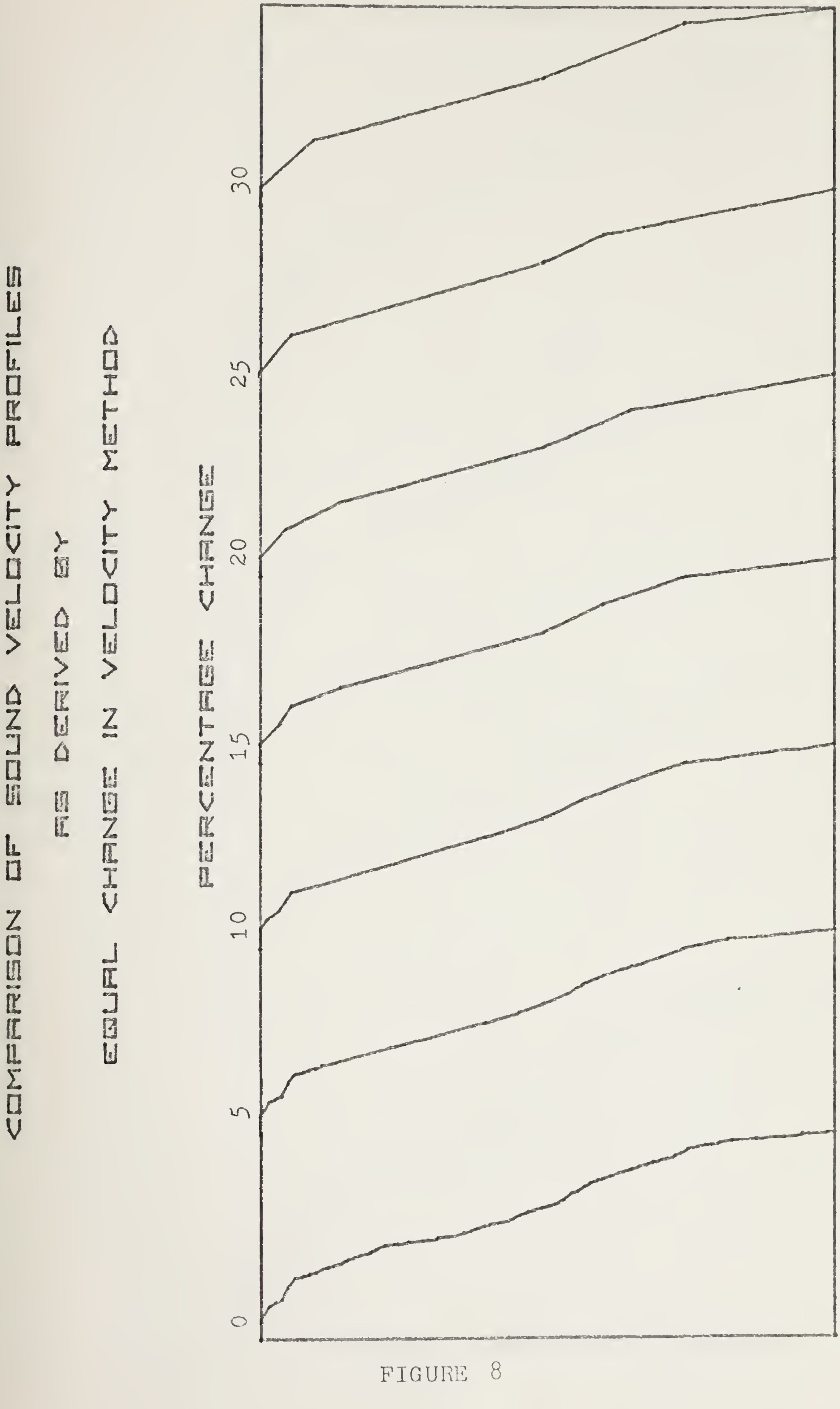

COMPARISON OF SOUND VELOCITY PROFILES
AS DERIVED BY
EQUAL CHANGE IN VELOCITY METHOD
PERCENTAGE CHANGE
0
5
10
15
20
25
30

FIGURE 8

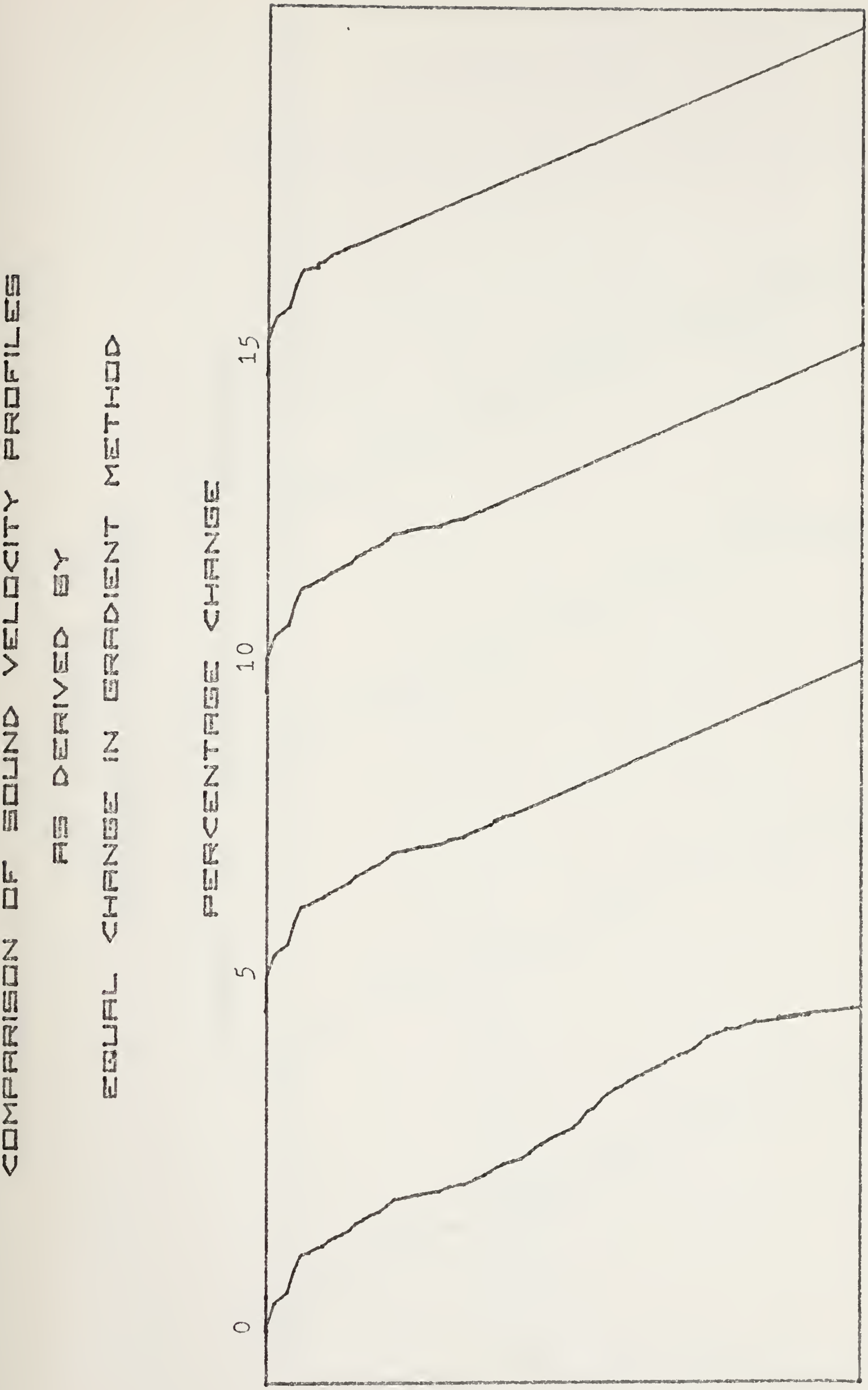

COMPARISON OF SOUND VELOCITY PROFILES
AS DERIVED BY
EQUAL CHANGE IN GRADIENT METHOD
PERCENTAGE CHANGE
0
5
10
15

FIGURE 9

COMPARISON OF SOUND VELOCITY PROFILES
AS DERIVED BY
"EYEBALL" METHOD

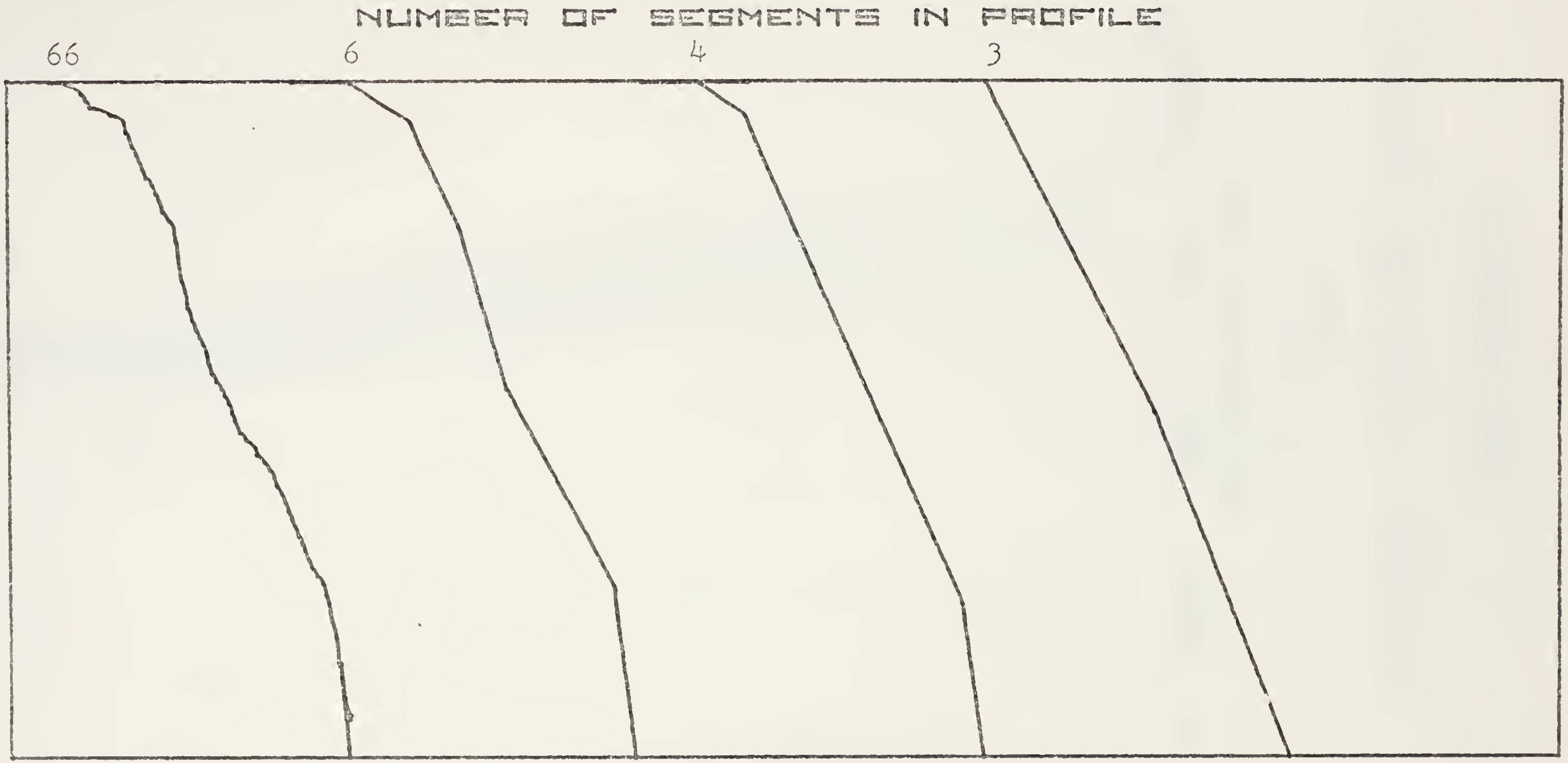


FIGURE 10

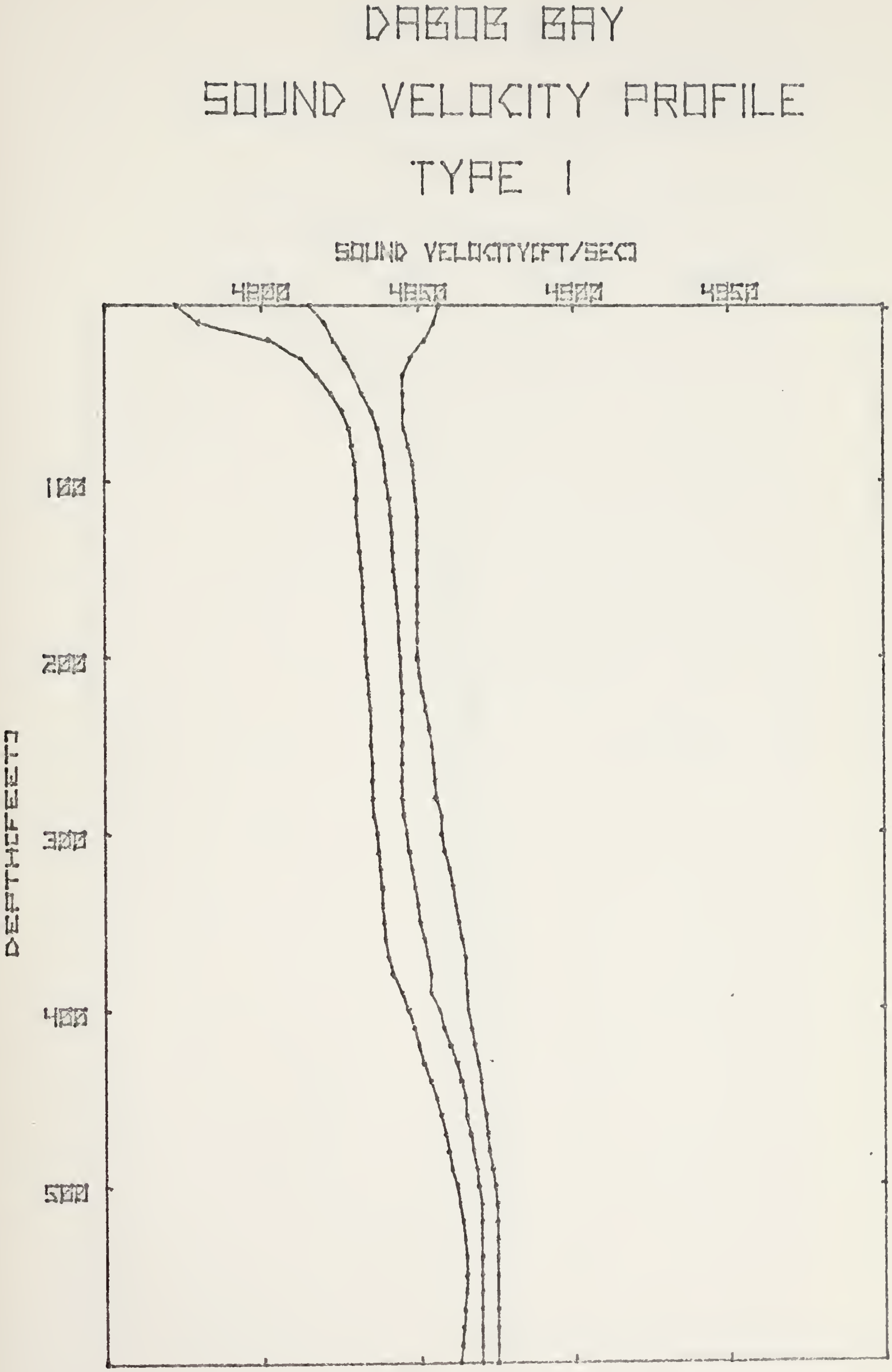
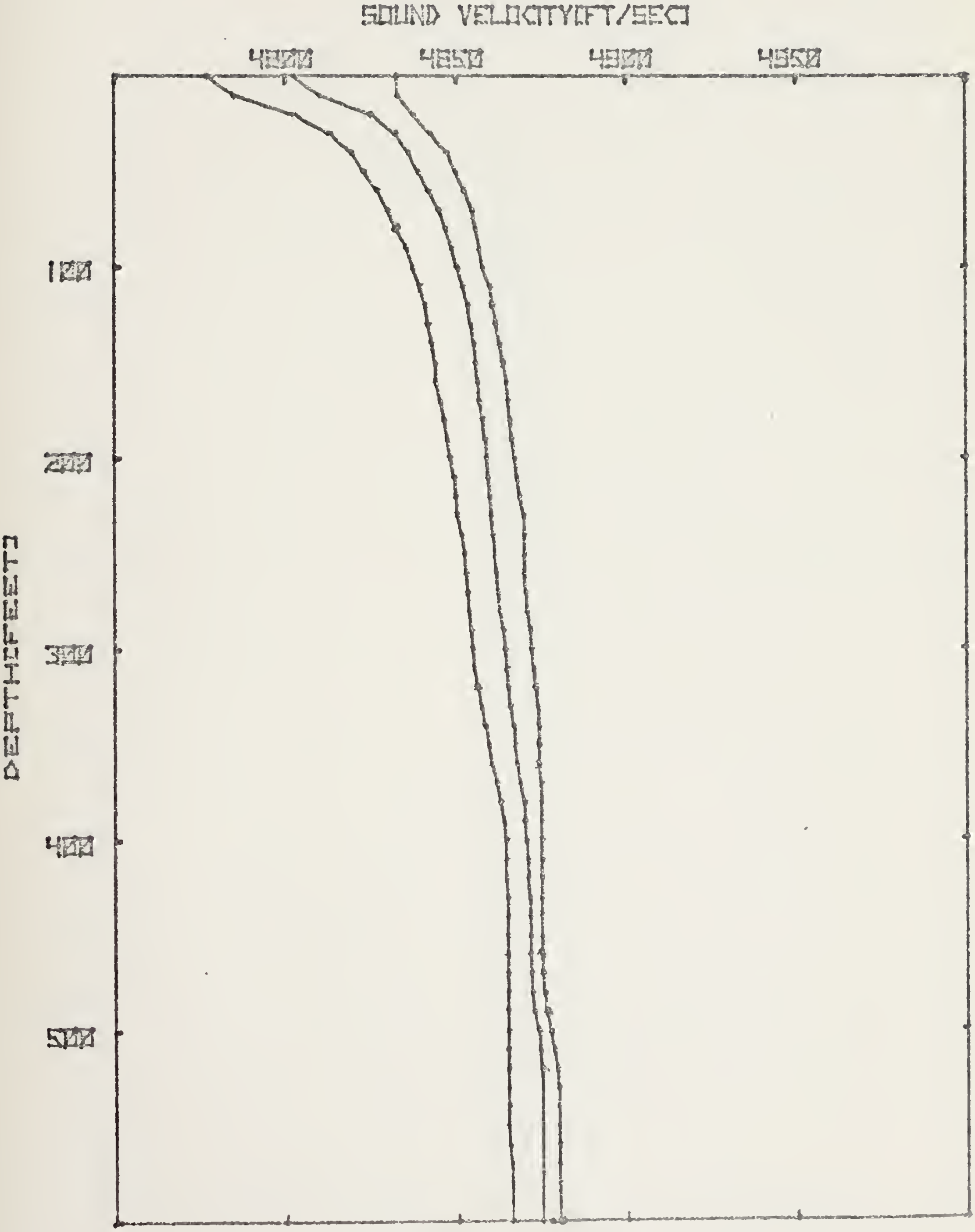

DABOB BAY
SOUND VELOCITY PROFILE
TYPE I
SOUND VELOCITY(FT/SEC)
4800
4850
4900
4950
DEPTH(FEET)
100
200
300
400
500

FIGURE 11



DABOB BAY

SOUND VELOCITY PROFILE

TYPE 2

FIGURE 12

DABOB BAY
SOUND VELOCITY PROFILE
TYPE 3

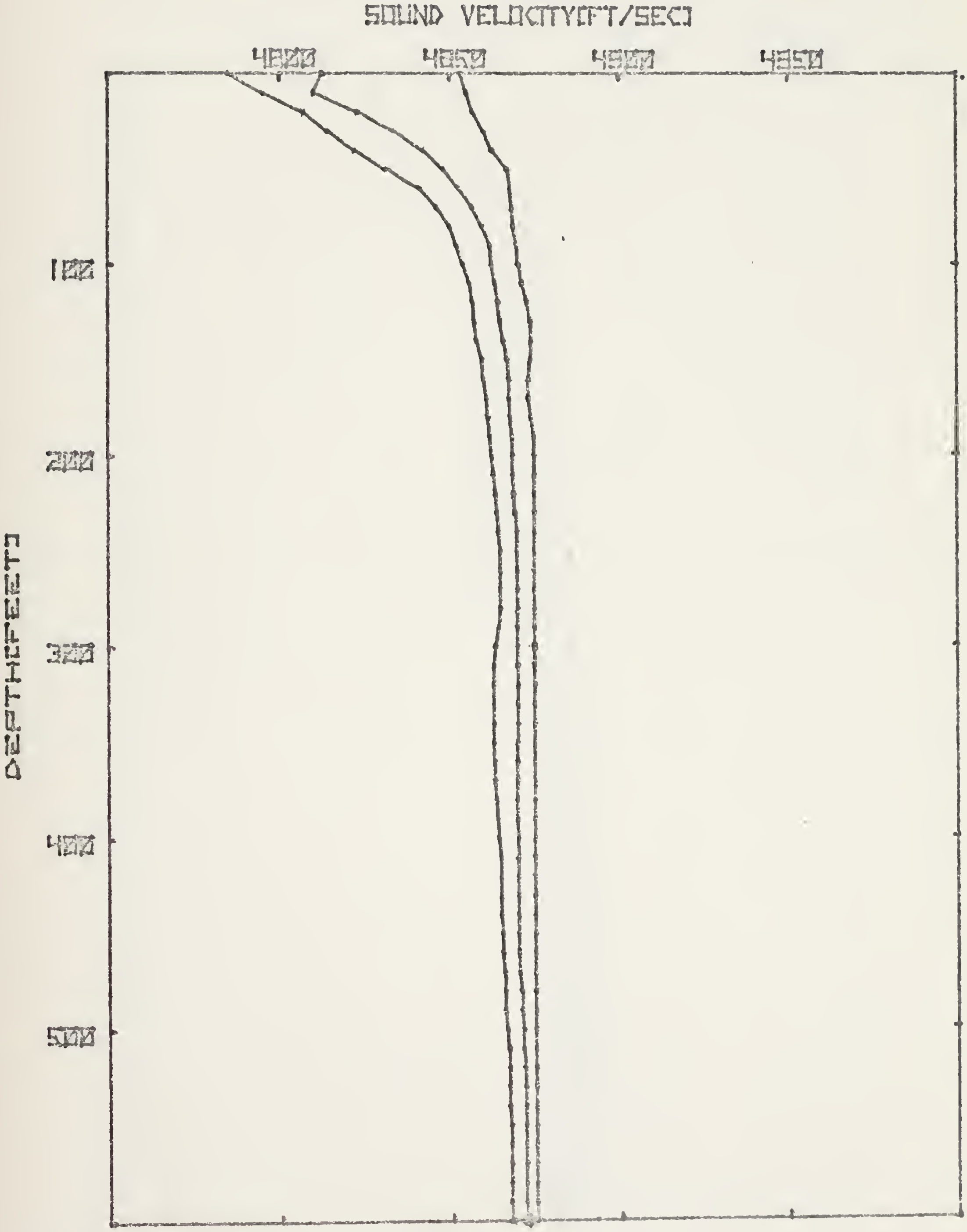


FIGURE 13

DABOB BAY
SOUND VELOCITY PROFILE
TYPE 4

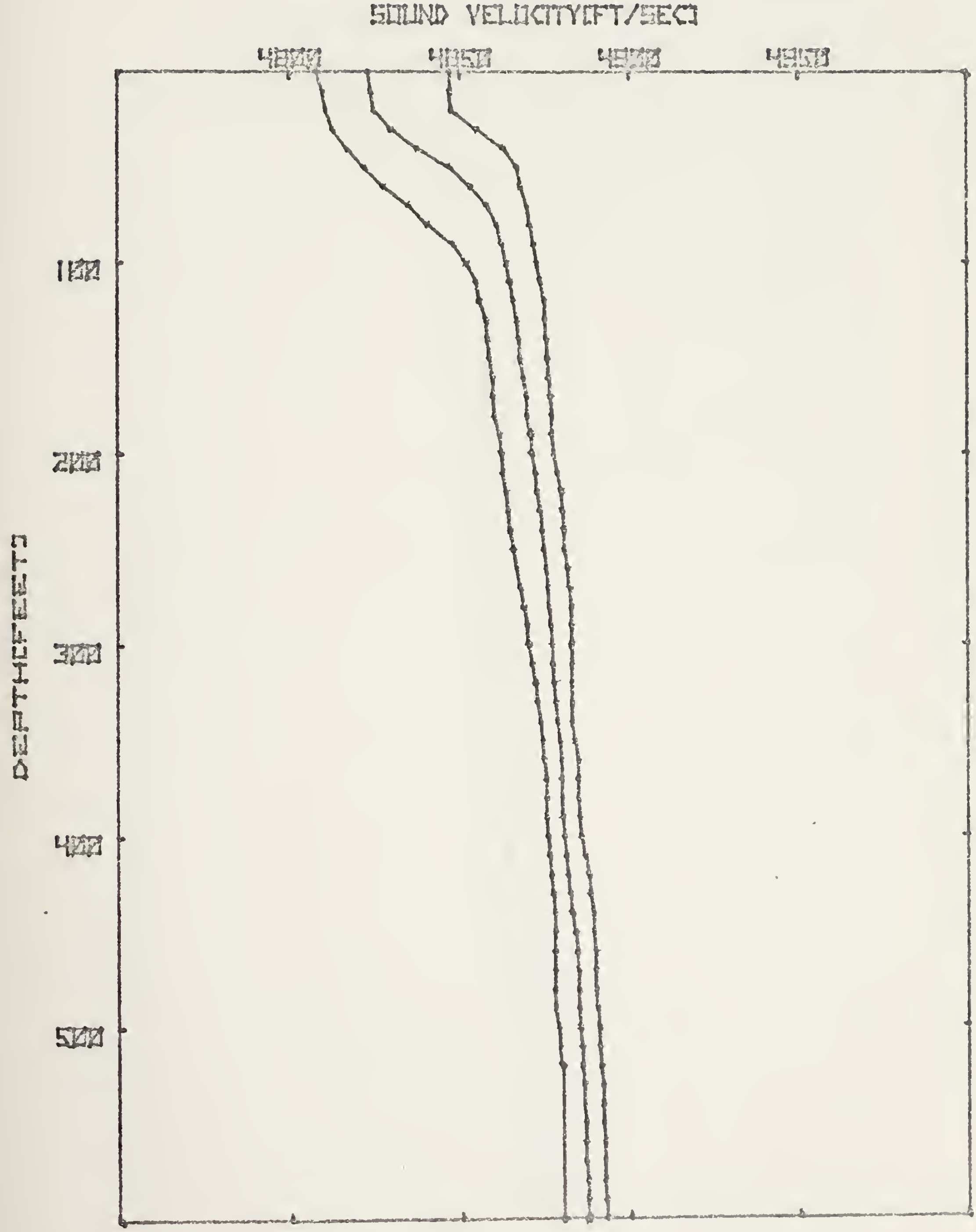
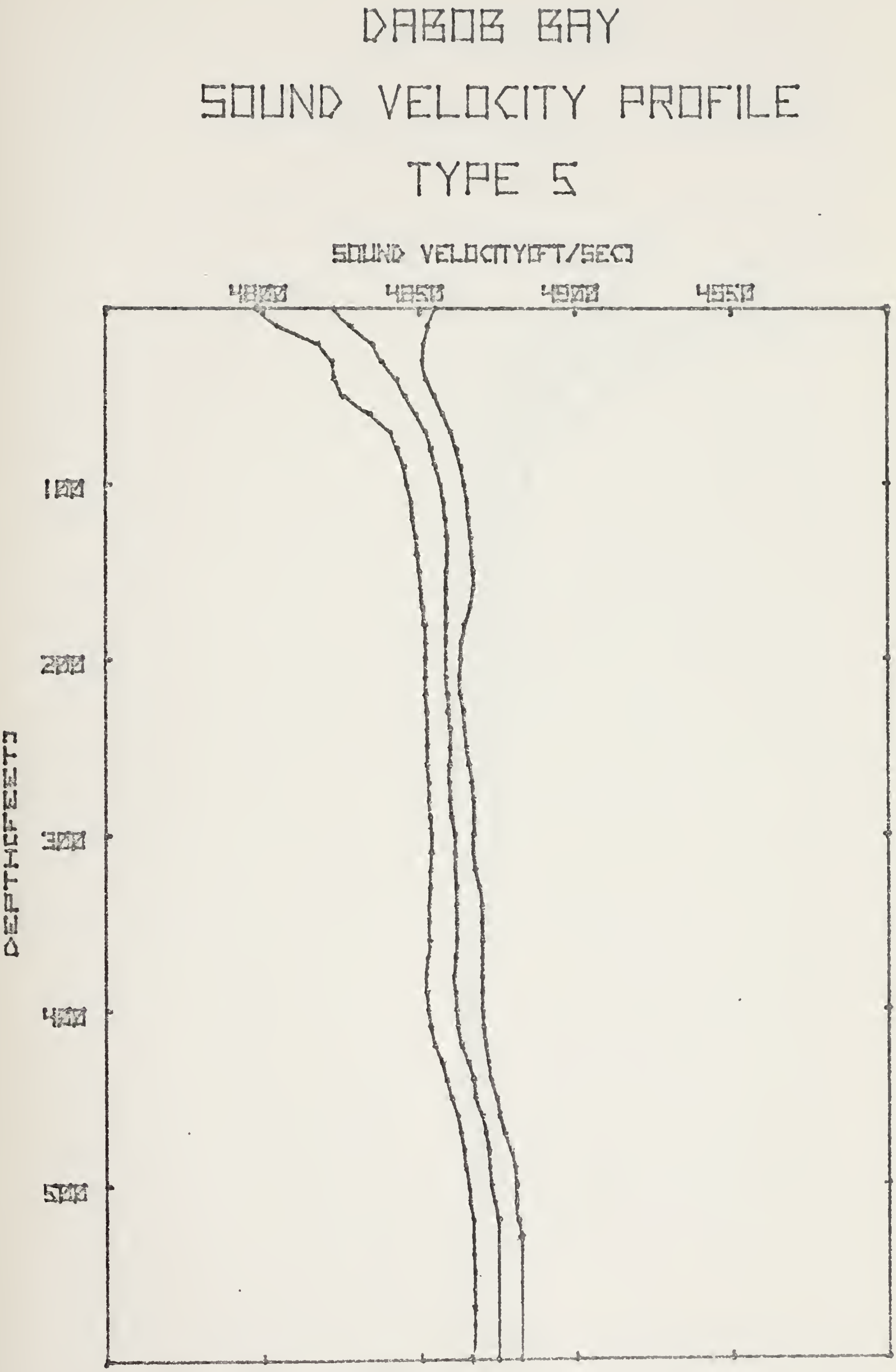


FIGURE 14



DABOB BAY

SOUND VELOCITY PROFILE

TYPE 5

FIGURE 15

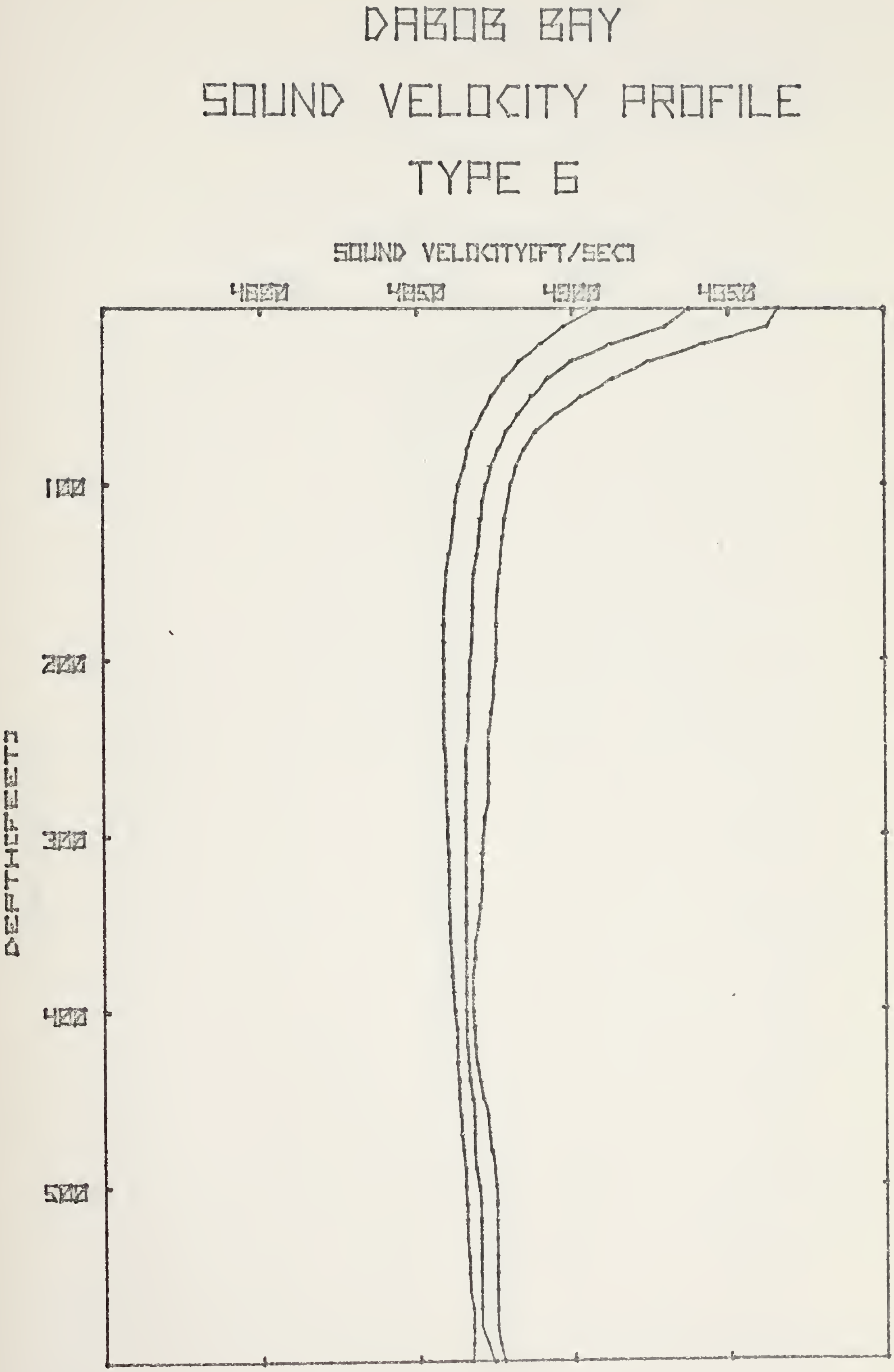

DABOB BAY
SOUND VELOCITY PROFILE
TYPE 6
SOUND VELOCITY(FT/SEC)
4800
4850
4900
4950
100
200
300
400
500
DEPTH(FEET)

FIGURE 16

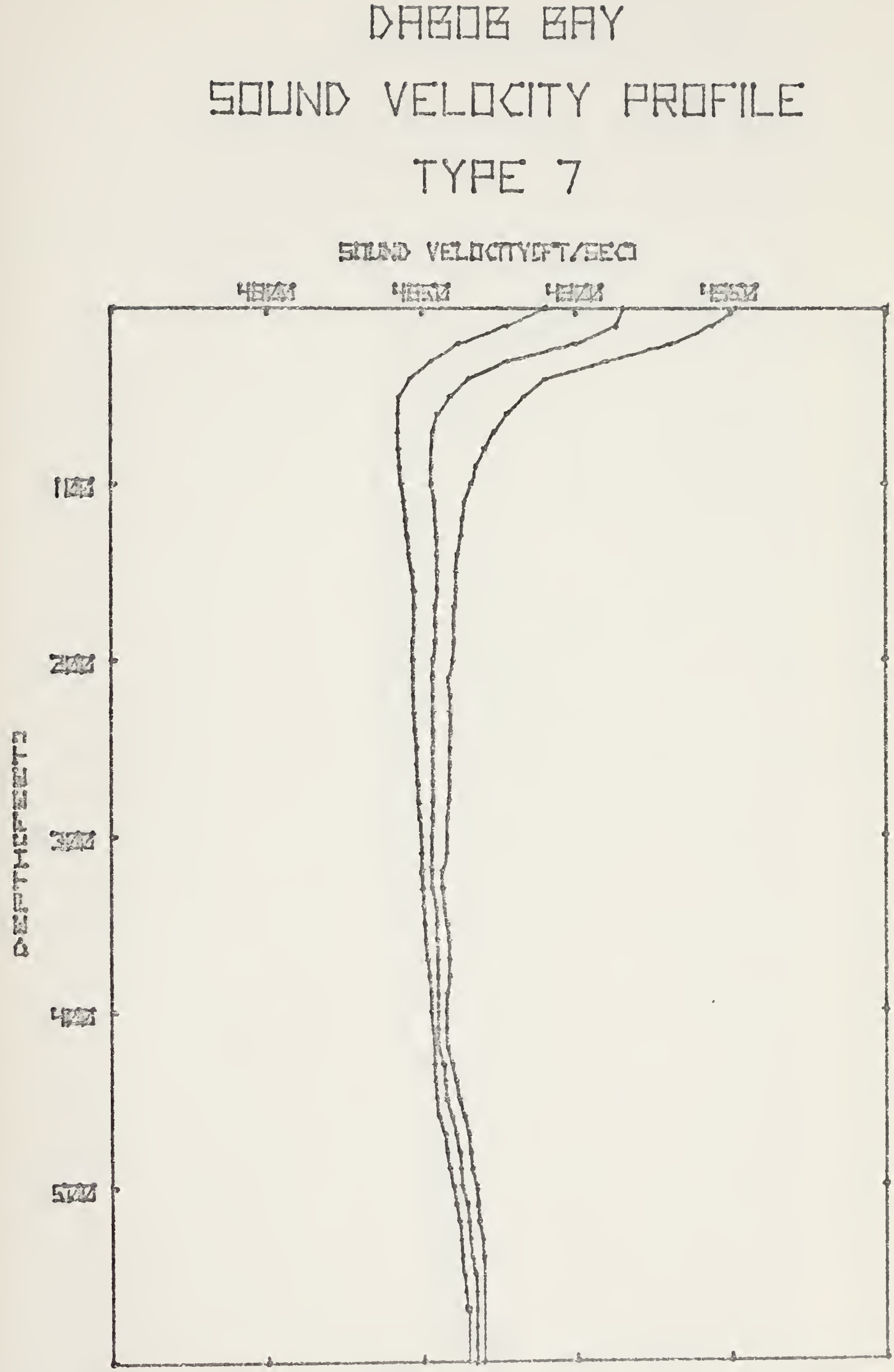

DABOB BAY
SOUND VELOCITY PROFILE
TYPE 7
SOUND VELOCITY(FT/SEC)
4800
4850
4900
4950
100
200
300
400
500
DEPTH(FEET)

FIGURE 17

DABOB BAY
SOUND VELOCITY PROFILE
TYPE B

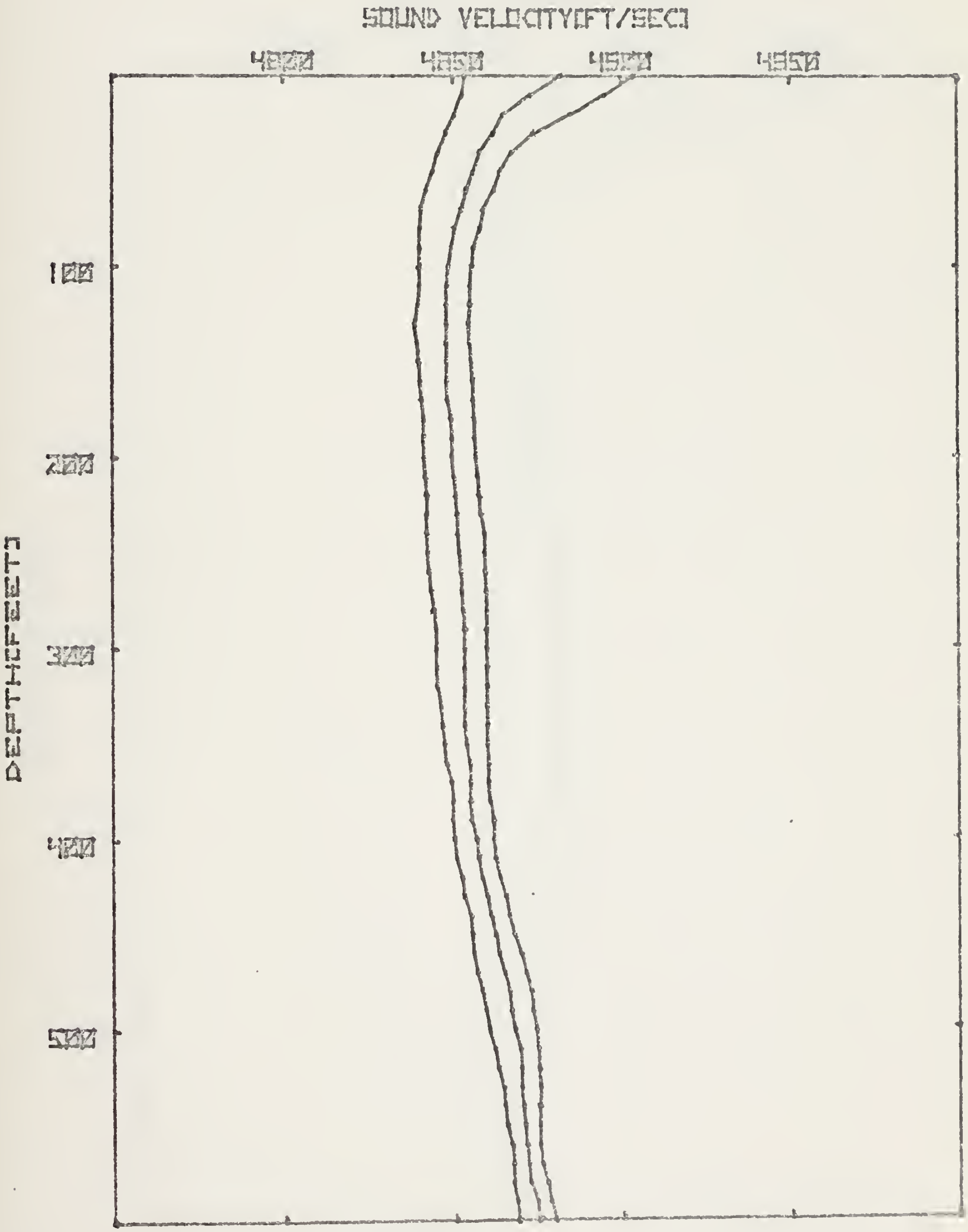


FIGURE 18

DABOB BAY
SOUND VELOCITY PROFILE
TYPE 9

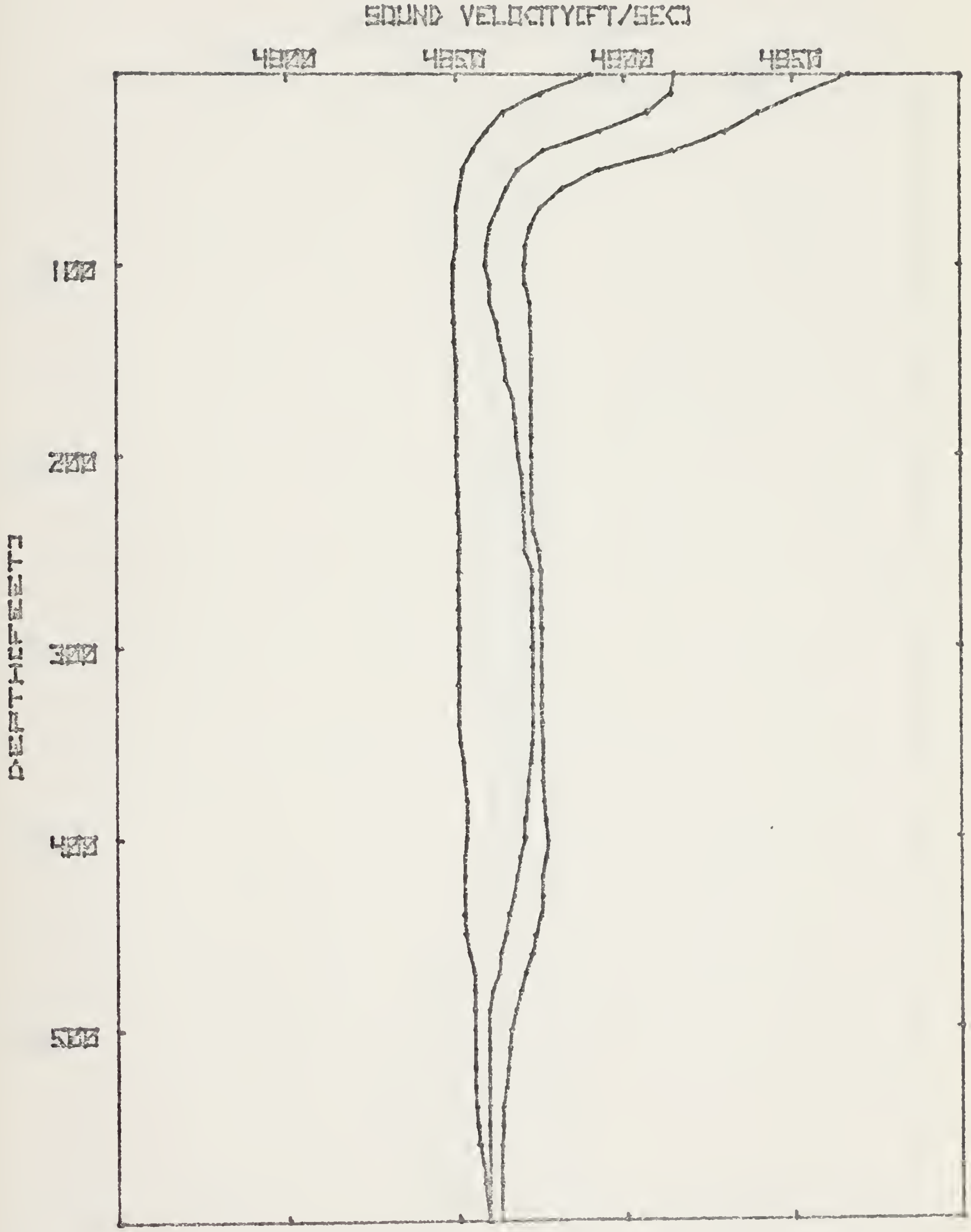


FIGURE 19

DABOB BAY
SOUND VELOCITY PROFILE
TYPE 10

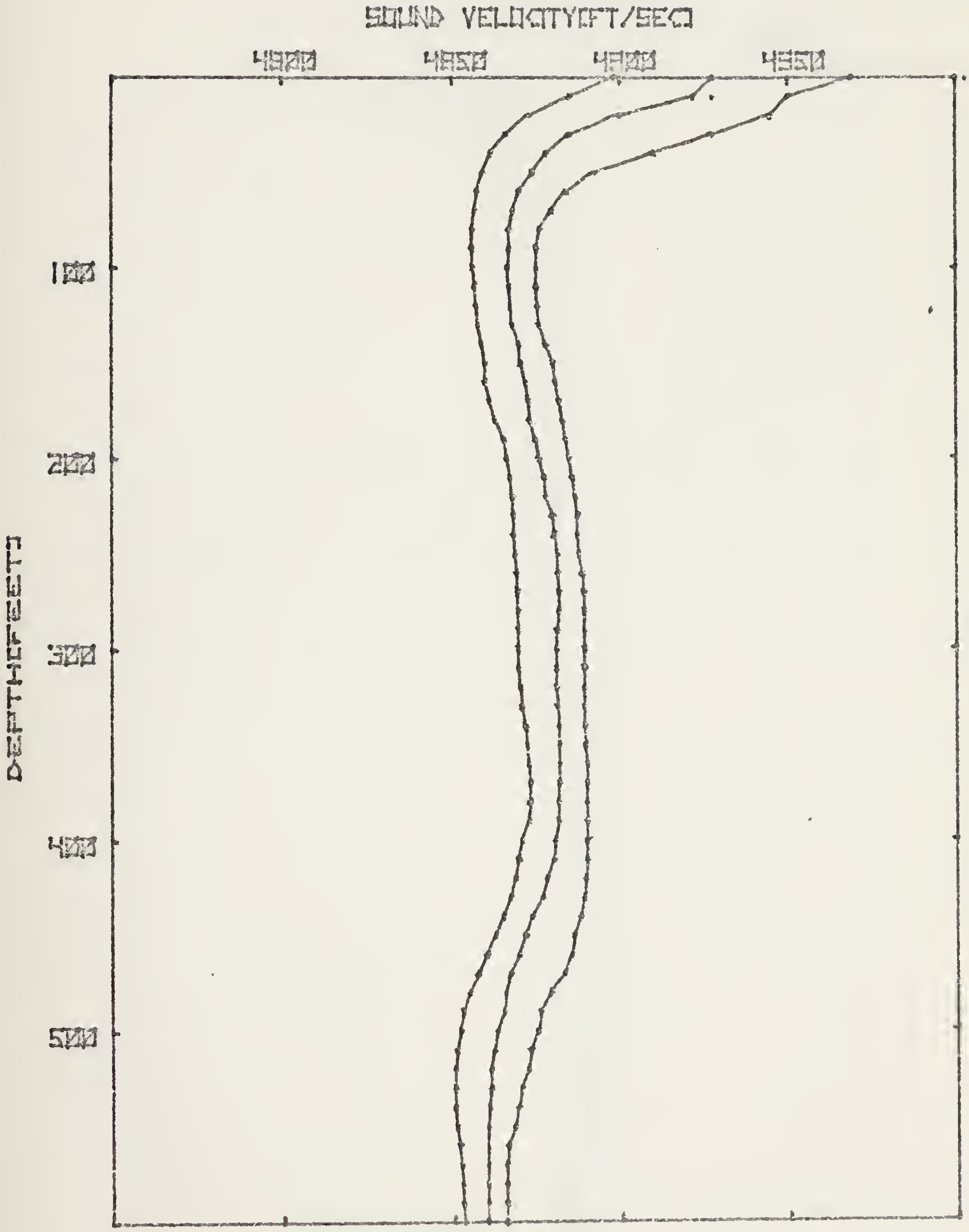
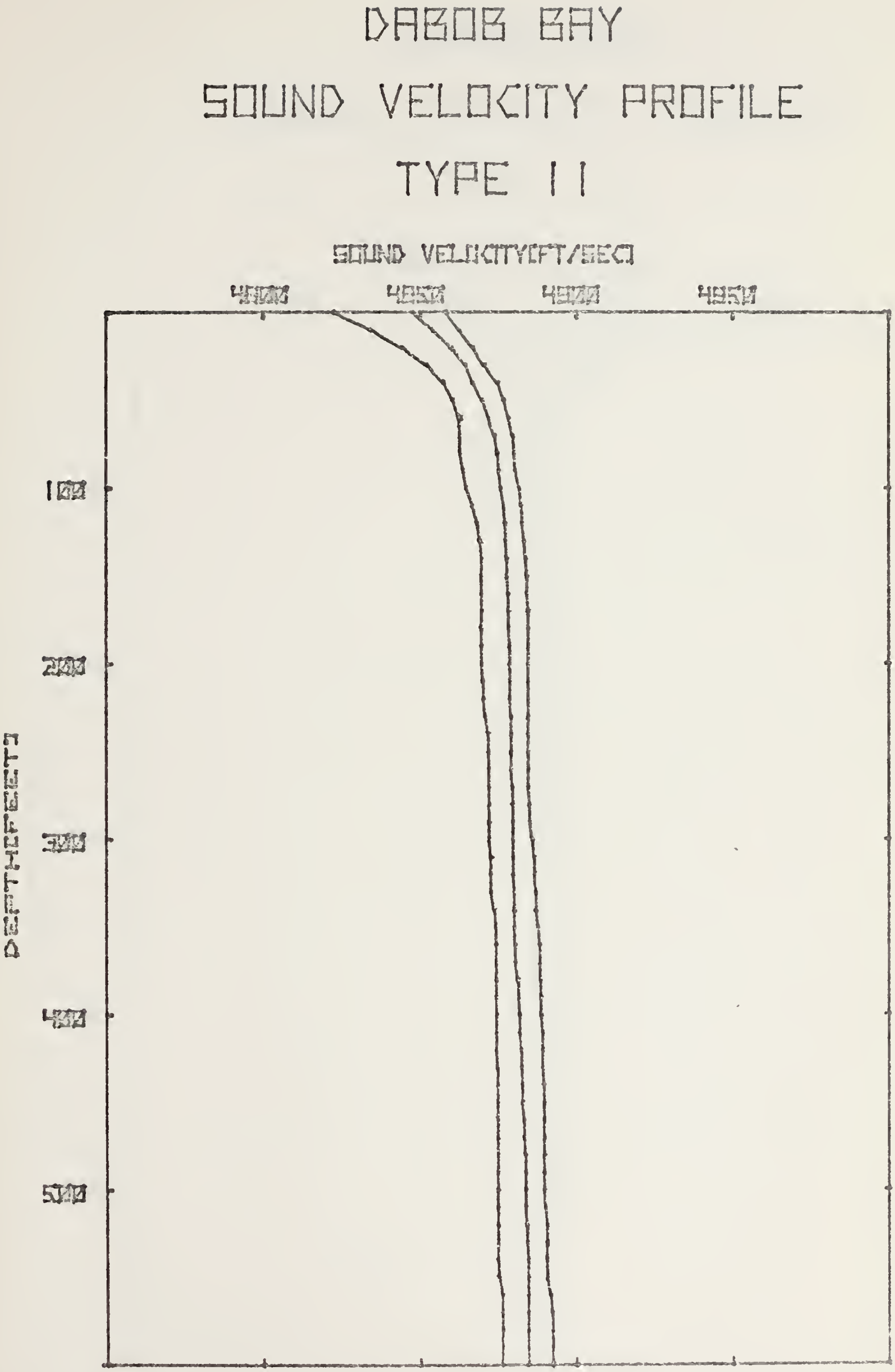


FIGURE 20



DABOB BAY
SOUND VELOCITY PROFILE
TYPE II

FIGURE 21

DABOB BAY
SOUND VELOCITY PROFILE
TYPE 12

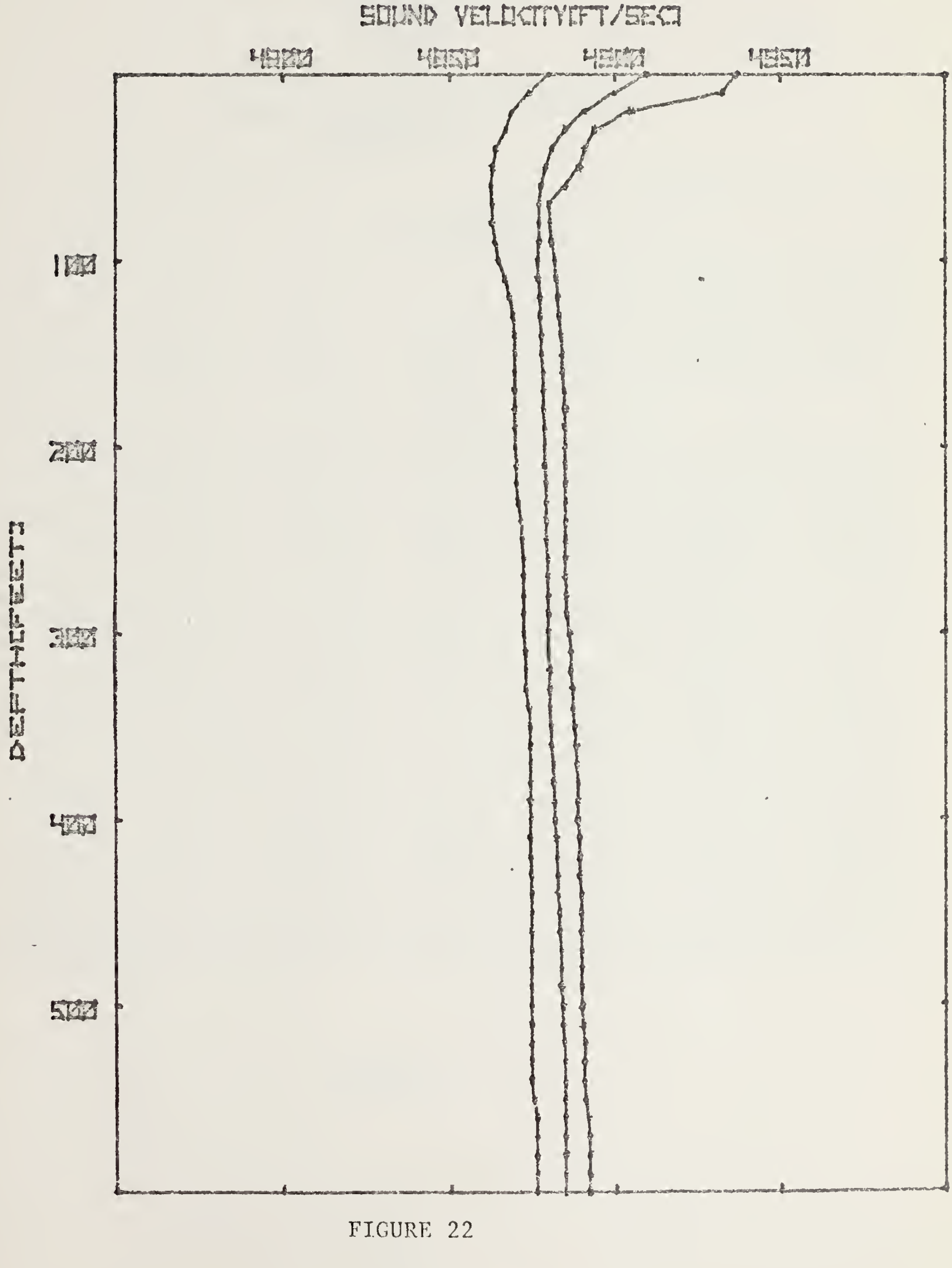


FIGURE 22

COMPONENT

THETA

STANDARD ERROR OF ESTIMATE
(DEGREES)

		DEPTH(FEET)					
		25	50	75	100	150	200
STATION	1	.066	.070	.060	.090	.074	.078
	2	.070	.086	.098			
	3	.059	.099	.112	.065	.087	.102
	4	.131	.035	.059	.053	.049	.028
	5	.146	.157	.038	.042	.028	.037
	6	.092	.092	.143	.078	.104	.095
	5P	.124	.042	.054	.051	.058	.041
	4P	.122	.069	.042	.028	.039	.069
	3P	.045	.030	.031	.027	.061	.046
	1P	.055	.046	.052	.050	.066	.079

TABLE I

COMPONENT

PHI

STANDARD ERROR OF ESTIMATE
(DEGREES)

		DEPTH(FEET)					
		25	50	75	100	150	200
STATION	1	.028	.031	.020	.021	.030	.030
	2	.085	.204	.199			
	3	.038	.042	.036	.035	.049	.032
	4	.031	.034	.037	.034	.034	.035
	5	.037	.034	.025	.048	.034	.042
	6	.062	.055	.078	.080	.096	.080
	5P	.039	.037	.035	.037	.036	.044
	4P	.038	.033	.037	.035	.052	.032
	3P	.032	.032	.030	.033	.049	.043
	1P	.028	.027	.033	.048	.030	.056

TABLE II

COMPONENT

R

STANDARD ERROR OF ESTIMATE
(FEET)

		DEPTH(FEET)					
		25	50	75	100	150	200
STATION	1	.186	.112	.178	.192	.249	.171
	2	1.330	2.505	1.700			
	3	.151	.212	.172	.199	.269	.154
	4	.197	.239	.238	.248	.296	.269
	5	.273	.269	.194	.192	.337	.286
	6	.409	.316	.366	.486	.414	.373
	5P	.314	.258	.232	.277	.375	.338
	4P	.251	.231	.230	.228	.280	.199
	3P	.165	.195	.178	.165	.202	.166
	1P	.190	.155	.167	.253	.211	.284

TABLE III

STANDARD ERROR OF ESTIMATE CAUSED BY ENVIRONMENTAL DESCRIPTION

BY VELOCIMETER

STA	DEPTH	COMPONENT		
		THETA (DEG)	PHI (DEG)	R (FT)
1	25	.067	.029	.187
	50	.073	.033	.114
	75	.062	.020	.175
	100	.094	.022	.199
	150	.076	.030	.248
	200	.082	.031	.175
6	25	.095	.055	.283
	50	.095	.056	.319
	75	.145	.079	.361
	100	.081	.076	.422
	150	.108	.098	.415
	200	.098	.081	.377

TABLE IV

STANDARD ERROR OF ESTIMATE OF R CAUSED BY ENVIRONMENTAL DESCRIPTION

BY THE EQUAL CHANGE IN VELOCITY METHOD

STA	DEPTH	PERCENTAGE CHANGE IN VELOCITY					
		5	10	15	20	25	30
1	25	.153	.166	.157	.165	.135	.158
	50	.142	.151	.149	.129	.214	.223
	75	.215	.140	.157	.154	.142	.155
	100	.156	.174	.165	.138	.154	.141
	150	.195	.157	.162	.172	.172	.158
	200	.145	.163	.163	.130	.146	.169
6	25	.269	.268	.252	.194	.258	.252
	50	.270	.241	.242	.267	.220	.246
	75	.268	.257	.314	.580	.319	.417
	100	.314	.246	.592	.214	.834	.383
	150	.415	.478	.274	.314	.319	.308
	200	.377	.315	.319	.289	.242	.984

TABLE V

STANDARD ERROR OF ESTIMATE OF R CAUSED BY ENVIRONMENTAL DESCRIPTION

BY THE EQUAL CHANGE IN GRADIENT METHOD

STA	DEPTH	PERCENTAGE CHANGE IN GRADIENT		
		5	10	15
1	25	.170	.168	.637
	50	.139	.151	.637
	75	.146	.103	.209
	100	.201	.157	.169
	150	.218	.187	.189
	200	.162	.138	.177
6	25	.413	.428	.435
	50	.247	.259	.271
	75	.259	.284	.295
	100	.330	.310	.318
	150	.310	.305	.299
	200	.334	.314	.305

TABLE VI

STANDARD ERROR OF ESTIMATE OF R
CAUSED BY ENVIRCNMENTAL DESCRIPTION

BY THE 'EYEBALL' METHOD

STA	DEPTH	NUMBER OF SEGMENTS			
		5	3	2	1
1	25	.176	.350	.172	.196
	50	.198	.167	.172	.204
	75	.162	.144	.130	.192
	100	.134	.148	.132	.165
	150	.177	.167	.172	.199
	200	.200	.140	.168	.161

		NUMBER OF SEGMENTS			
		6	4	3	1
6	25	.241	.240	.210	**
	50	.239	.187	.267	**
	75	.118	.179	.179	**
	100	.229	.277	.235	.245
	150	.298	.230	.209	.408
	200	.441	.207	**	.210

** INDICATES STANDARD ERROR GREATER THAN 1.000

TABLE VII

STANDARD ERRORS OF ESTIMATE OF APPROXIMATED PROFILES
AS DERIVED FROM HISTORICAL PROFILE 4

PERCENTAGE CHANGE	COMPARED WITH OWN PROFILE						COMPARED WITH MID PROFILE			
	MID		MIN		MAX		MIN		MAX	
	PHI (DEG)	R (FT)	PHI (DEG)	R (FT)	PHI (DEG)	R (FT)	PHI (DEG)	R (FT)	PHI (DEG)	R (FT)
5	0.711	4.181	0.579	4.165	0.722	2.928	0.579	4.225	0.722	3.153
10	0.713	4.080	0.589	4.295	0.722	3.259	0.589	4.316	0.722	3.092
15	0.100	3.017	0.035	0.089	0.773	3.702	0.003	0.931	0.723	3.611
20	0.712	2.828	0.551	1.760	0.723	2.807	0.552	1.712	0.723	2.543
25	0.710	2.211	0.564	1.708	0.723	2.663	0.564	1.772	0.723	2.472
30	0.147	10.948	0.088	2.072	0.723	2.663	0.564	1.772	0.723	2.472

* STANDARD ERRORS CALCULATED BETWEEN SURFACE AND 200 FEET

TABLE VIII

STANDARD ERRORS OF ESTIMATE OF APPROXIMATED PROFILES
AS DERIVED FROM HISTORICAL PROFILE.4

PERCENTAGE CHANGE	COMPARED WITH OWN PROFILE						COMPARED WITH MID PROFILE			
	MID		MIN		MAX		MIN		MAX	
	PHI (DEG)	R (FT)	PHI (DEG)	R (FT)	PHI (DEG)	R (FT)	PHI (DEG)	R (FT)	PHI (DEG)	R (FT)
5	0.712	2.911	0.546	2.956	0.726	2.761	0.546	2.953	0.726	2.739
10	0.711	2.300	0.559	2.933	0.726	2.675	0.559	2.927	0.726	2.651
15	0.088	0.874	0.032	1.010	0.726	3.212	0.033	1.019	0.727	3.192
20	0.770	1.476	0.656	1.405	0.727	1.399	0.656	1.366	0.727	1.347
25	0.817	1.417	0.562	1.279	0.724	1.490	0.562	1.245	0.724	1.442
30	0.098	1.500	0.066	1.499	0.724	1.490	0.066	1.492	0.724	1.442

* STANDARD ERRORS CALCULATED BETWEEN 100 AND 300 FEET

TABLE IX

COMPARISON OF STANDARD ERRORS CAUSED BY THE APPROXIMATION OF SOUND VELOCITY PROFILES BY THE EQUAL CHANGE IN VELOCITY METHOD

	STANDARD ERROR			
	RANGE OF CALCULATIONS			
	0 - 200 FT		100 - 300 FT	
PER CENT CHANGE	PHI (DEG)	R (FT)	PHI (DEG)	R (FT)
5	0.028	1.629	0.031	1.684
10	0.031	1.988	0.031	1.844
15	0.016	3.306	0.011	1.451
20	0.041	5.179	0.037	1.681
25	0.042	6.086	0.034	1.961
30	0.023	6.213	0.012	2.048

TABLE X

APPENDIX A

ISOGRAD

```
C       EQUAL CHANGE IN GRADIENT METHOD
C
C
C       THIS PROGRAM COMPUTES APPROXIMATED SOUND VELOCITY PROFILES
C
C       FROM ANY PROFILE AT POINTS OF EQUAL CHANGE IN GRADIENT
C
C       FROM THE BOTTOM.
C
C
C       INPUTS REQUIRED
           1.   NUMBER OF POINTS IN PROFILE(FORMAT - I2)
C          2.   DEPTH - VELOCITY POINTS(4 PER CARD) IN PROFILE
C               (FORMAT - F10.1, F10.2)
C
C
C       OUTPUT
C       SOUND VELOCITY PROFILE AT 5, 10, AND 15 PERCENT CHANGE
C
C       INCREMENTS IN GRADIENT.
C
C
C
        DIMENSION DPH(75),V(75),VX(75),DX(75)
        DOUBLE PRECISION XN,SX,SY,SXY,SX2
    100 FORMAT(I2,3I10)
    200 FORMAT(4(F10.1,F10.2))
    300 FORMAT(1X,I2,5X,F5.1,5X,F7.2)
    700 FORMAT(I2,3I10)
        DO 400 ILY=1,2
        READ(5,100) ISTA,IDEP,ISVP,ITIME
        READ(5,200) (DPH(I),V(I), I=1,ISVP)
        IS=ISVP/2
        DO 50 I=1,IS
        K=ISVP-I+1
        VX(1)=V(I)
        VX(2)=V(K)
        V(I)=VX(2)
        V(K)=VX(1)
        DX(2)=DPH(K)
        DX(1)=DPH(I)
        DPH(I)=DX(2)
```

```
      DFH(K)=DX(1)
   50 CONTINUE
      DO 60 I=1,ISVP
   60 CONTINUE
      DC 20 I1=1,3
      XV=.05*FLOAT(I1)
      I=1
      J=3
      K=1
   34 II=I
      III=J
      XN=FLOAT(J-I+1)
      IF(XN-2.) 30,31,32
   32 SX=0.
      SY=0.
      SXY=0.
      SX2=0.
      DO 2 IX=II,III
      SX=SX+DPH(IX)
      SY=SY+V(IX)
      SX2=SX2+DPH(IX)*DPH(IX)
    2 SXY=SXY+V(IX)*DPH(IX)
      GRAD1=-1.*((XN*SXY)-(SX*SY))/((XN*SX2)-(SX*SX))
      DGRAD=ABS(XV*GRAD1)
    6 J=J+1
      IF(J.GT.ISVP) GO TO 33
      GRAD2=(V(J)-V(I))/(DPH(I)-DPH(J))
      TEST=ABS(GRAD2-GRAD1)
   41 IF(TEST.LE.DGRAD) GO TO 6
      XN=FLOAT(J-I)
      IF(XN.EQ.3.) GO TO 33
      II=III+1
      III=J-1
      J=J-1
      DO 7 IY=II,III
      SX=SX+DPH(IY)
      SX2=SX2+DPH(IY)*DPH(IY)
      SY=SY+V(IY)
    7 SXY=SXY+V(IY)*DPH(IY)
      A1=((XN*SXY)-(SX*SY))/((XN*SX2)-(SX*SX))
   35 A0=((SY*SX2)-(SX*SXY))/((XN*SX2)-(SX*SX))
      VCC =A0+A1*DPH(I)
      IF(K.EQ.1) VXX=VCC
      VX(K)=VXX-(VXX-VCC)/2.
      DX(K)=DPH(I)
      K=K+1
      VXX =A0+A1*DPH(J)
      IF(J.EQ.ISVP) GO TO 38
```

```
      I=J
      J= I+2
      IF(J.EQ.ISVP) J=ISVP
      GO TO 34
   33 A1=-GRAD1
      J=J-1
      GO TO 35
   30 VX(K)=VXX
      DX(K)=585.
      GO TO 11
   38 VX(K)=VXX
      DX(K)=0.
      GO TO 11
   31 VX(K)=VXX-(VXX-V(I))/2.
      DX(K)=DPH(I)
      K=K+1
      I=I+1
      VX(K)=VXX
      DX(K)=0.
   11 IS=K/2
      L=K
      DO 70 I=1,IS
      K=IS-I+1
      CH1=V(I)
      CH2=V(K)
      V(I)=CH2
      V(K)=CH1
      CH1=DPH(I)
      CH2=DPH(K)
      DPH(I)=CH2
      DPH(K)=CH1
   70 CONTINUE
      DPH(L)=585.
      WRITE(6,300) (I,DPH(I), V(I), I=1,L)
      WRITE(7,700) ISTA,IDEP,L,ITIME
      WRITE(7,200) (DPH(I),V(I), I=1,L)
   20 CONTINUE
  400 CONTINUE
   99 STOP
      END
```

APPENDIX B

ISOVEL

```
C     EQUAL CHANGE IN VELOCITY METHOD
C
C
C     THIS PROGRAM COMPUTES APPROXIMATED SOUND VELOCITY PROFILES
C
C     FROM ANY PROFILE AT POINTS OF EQUAL CHANGE IN VELOCITY
C
C     BETWEEN THE GIVEN PROFILE'S MINIMUM AND MAXIMUM VELOCITIES
C
C     AND ITS MINUMUM AND MAXIMUM POINTS.
C
C
C     INPUTS REQUIRED
         1.   NUMBER OF POINTS IN PROFILE(FORMAT - I2)
C        2.   DEPTH - VELOCITY POINTS(4 PER CARD) IN PROFILE
C             (FORMAT - F10.1, F10.2)
C
C
C     OUTPUT
C     SOUND VELOCITY PROFILE AT 5, 10, 15, 20, 25, AND 30 PERCENT
C
C     CHANGE INCREMENTS IN VELOCITY
C
C
C
      DIMENSION VV(3,70),V(3,70),DD(3,70),D(3,70)
      DIMENSION DY(2),VX(2)
  200 FORMAT(4(5X,F5.1,5X,F7.2))
  400 FORMAT(4(F10.1,F10.2))
  600 FORMAT(1X,I3)
  800 FORMAT(I2)
      DO 1 II=1,2
      IFL=1
      XMA=-100.
      XMI=9000.
      READ(5,800) ISTA
      READ(5,400) (DD(II,KK),VV(II,KK), KK=1,ISVP)
      IS=ISVP/2
      DO 50 I=1,IS
      K=ISVP-I+1
      VX(1)=VV(II,I)
      VX(2)=VV(II,K)
```

```
      VV(II,I)=VX(2)
      VV(II,K)=VX(1)
      DY(1)=DD(II,I)
      DY(2)=DD(II,K)
      DD(II,I)=DY(2)
      DD(II,K)=DY(1)
   50 CONTINUE
      DO 6 I=1,ISVP
      V(II,I)=VV(II,I)
      D(II,I)=DD(II,I)
      XMA=AMAX1(XMA,VV(II,I))
      XMI=AMIN1(XMI,VV(II,I))
    6 CONTINUE
      DO 60 I=1,ISVP
      IF(VV(II,I).EQ.XMI) GO TO 51
   60 CONTINUE
   51 K5=I
      M=ISVP
      DV=XMA-XMI
      DO 7 I=1,6
      IF(IFL.LE.1) GO TO 40
   44 DX=.05*DV*FLOAT(I)
      V(II,1)=VV(II,1)
      D(II,1)=0.
      VT=V(II,1)
      IFM=0
      IFMI=0
      IF(VV(II,1).EQ.XMA) IFM=1
      IF(VV(II,1).EQ.XMI) IFMI=1
      K=2
      M=2
   30 T1=VT+DX
      T2=VT-DX
   10 IF(IFM) 99,8,9
    8 IF(IFMI) 99,11,12
   12 IF(VV(II,K)-VT) 13,14,15
   13 IF(T2.GE.VV(II,K)) GO TO 16
   14 K=K+1
      IF(K.EQ.ISVP) GO TO 31
      GO TO 10
   15 IF(VV(II,K).EQ.XMA) GO TO 17
   19 IF(T1.GT.VV(II,K)) GO TO 14
      V(II,M)=T1
      GO TO 18
   16 V(II,M)=T2
      GO TO 18
   17 IF(T1.LT.VV(II,K)) GO TO 19
      V(II,M)=XMA
```

```
      IFM=1
      GO TO 18
    9 IF(IFMI) 99,20,21
   21 IF(VV(II,K)-VT) 22,23,24
   22 IF(T2.LT.VV(II,K)) GO TO 23
      V(II,M)=T2
      GO TO 18
   23 K=K+1
      IF(K.EQ.61) GO TO 31
      GO TO 10
   24 IF(T1.GT.VV(II,K)) GO TO 23
      V(II,M)=T1
      GO TO 18
   11 IF(XMI.LE.VT.AND.XMI.GE.T2) GO TO 52
      GO TO 12
   20 IF(XMI.LE.VT.AND.XMI.GE.T2) GO TO 25
      GO TO 21
   25 IF(K5.GT.K) GO TO 21
      GO TO 53
   52 IF(K5.GT.K) GO TO 12
   53 V(II,M)=XMI
      K=K5
      IFMI=1
      D(II,M)=DD(II,K)
      M=M+1
      GO TO 30
   18 IF(IFMI) 99,27,28
   27 IF(V(II,M).EQ.XMI) GO TO 26
   28 J=K-1
      D(II,M)=DD(II,J)+(VV(II,J)-V(II,M))/(VV(II,J)-VV(II,K))*
     1(DD(II,J)-DD(II,K))
      PROP=(V(II,M)-VV(II,J))/(VV(II,K)-VV(II,J))
      D(II,M)=DD(II,J)+(PROP*(DD(II,K)-DD(II,J)))
       VT=V(II,M)
      M=M+1
      GO TO 30
   26 IFMI=1
      GO TO 28
   31 V(II,M)=VV(II,ISVP)
      D(II,M)=DD(II,ISVP)
   40 K2=M/2
      K1= ISVP
      DO 41 K3=1,K2
      K4=K1-K3+1
      VH=V(II,K3)
      V(II,K3)=V(II,K4)
      V(II,K4)=VH
      DH=D(II,K3)
```

```
      D(II,K3)=D(II,K4)
      D(II,K4)=DH
   41 CCNTINUE
      D(II,1 )=585.
      WRITE(6,800) ISTA
      WRITE(7,400) (D(II,N),V(II,N),N=1,M)
      WRITE(6,200) (D(II,N),V(II,N),N=1,M)
      IFL=IFL+1
      IF(IFL-2)  7,44,7
    7 CONTINUE
    1 CONTINUE
   99 STCP
      END
```

APPENDIX C

SUBROUTINE ANGCAL

```
C     SUBROUTINE ANGCAL
C
C     THIS SUBROUTINE SIMULATES AN ACOUSTIC RAY FROM A FIXED
C
C     POSITION OF A SOURCE TO A RECEIVING ARRAY.  IT DETERMINES
C
C     THE APPARENT POSITION OF THE SOURCE AND THE INPUTS
C
C     REQUIRED FOR ENTRY INTO STUTRACK I.  THE SUBROUTINE IS
C
C     USED TO STUDY THE EFFECTS OF VARYING ENVIRONMENTAL
C
C     CONDITIONS BASED ON THE MOST DETAILED SOUND VELOCITY
C
C     PROFILE AVAILABLE.
      SUBROUTINE ANGCAL(KK,K5)
      COMMON
     1/COM/ T(150),GG(150),XA(150),X1(150),X2(150),H(150)
      COMMON/COM2/  D(100),V(100)
      DIMENSION GDV(60),GIN(60),VG(60)
      DIMENSION TEST(3),XG(155),HH(3)
      DIMENSION  RH(3),ZG(3),S(3)
      DIMENSION RG(3),     TX(3),AN(155),A(3),      G(70),DZ(70)
      DOUBLE PRECISION T
  100 FORMAT(4(F10.1,F10.2))
  200 FORMAT(8(4X,E12.5))
C
C  X-Y  KNOWN POSITION OF SOURCE
C
      Y=-1800.
      X=-4300.
      FAC=.0174532
      READ(5,100) (D(I),V(I),I=1,KK  )
  107 FORMAT(4(5X,F10.1,5X,F10.2))
      VSM=0.
      DO 1 I=1,KK
      J=I+1
      DZ(I)=D(I)-D(J)
      G(I)=(V(J)-V(I))/DZ(I)
      IF(G(I).EQ.0.) GO TO 2
      GIN(I)=1./G(I)
```

```
      GDV(I)=G(I)*DZ(I)/V(I)
      VG(I)=-V(I)*GIN(I)
      GO TO 40
    2 G(I)=999.
   40 VSM=VSM+((V(J)+V(I))*.5*DZ(I))
    1 CONTINUE
      VO=VSM/585.
      WRITE(6,200) VO
C
C  K5  NUMBER OF DEPTH INCREMENTS DESIRED
C
  123 DO 5 K=1,K5
      IFL=0
      A(1)=30.*FAC
      A(2)=5.  *FAC
      A(3)=1.5*FAC
C
C  SD  INITIAL DEPTH WHICH CALCULATIONS ARE TO START
C
C  INC  NUMBER OF FEET BETWEEN INCREMENTS
C
      SD=585.
      INC=4
      IZ=IFIX(SD)-K*INC
      Z=FLOAT(IZ)
      ZST=Z*Z
      R=SQRT(X*X+Y*Y+Z*Z)
      H(K)=SQRT(R*R-ZST)
      R=H(K)
C
C  AD  ARRAY DEPTH
C
      AD=585.
      Z=AD-Z
   25 DO 3 I=1,3
  113 RT=0.
      EN=A(I)
      IS=KK-1
      DO 4 J=1,IS
      L=J+1
  106 IF(D(J).GE.Z.AND.D(L).LE.Z) GO TO 6
  108 IF(G(J).EQ.999.) GO TO 7
  110 AA=((         GDV(J))+1.)*COS(EN)
      IF(AA.GT.1.)    GO TO 109
  102 EX=ARCOS(AA)
       GO TO 12
    7 EX=EN
       DR=DZ(J)/TAN(EN)
```

```
      GO TO 12
   10 DR=       ((VG(J)/COS(EN)))*(SIN(EX)-SIN(EN))
   12 RT=RT+DR
      EN=EX
    4 CONTINUE
   13 EX=EN
       DR=DM/TAN(EN)
      GO TO 18
  109 IF(I.EQ.2.AND.A(2).LT.A(1)) GO TO 120
      GO TO 121
  120 A(2)=A(2)+FAC
      GO TO 113
  121 IF(I.EQ.3) GO TO 122
  124 K4=K4+1
      K5=K5+1
      GO TO 123
  122 IF(TEST(1).LE.R.AND.TEST(2).GE.R) GO TO 22
      GO TO 124
    6 DM =D(J)-Z
      IF(G(J).EQ.999.) GO TO 13
  112 AA=((DM/DZ(J)*GDV(J))+1.)*COS(EN)
  104 EX=ARCOS(AA)
      DR=       ((VG(J)/COS(EN)))*(SIN(EX)-SIN(EN))
   18 RT=RT+DR
      EN=EX
      TEST(I)=RT
      RTEST=ABS(TEST(I)-R)
      IF(RTEST.LE..1 ) GO TO 31
    3 CONTINUE
      IF(TEST(1).LE.R.AND.TEST(3).GE.R) GO TO 19
      IF(TEST(1).GE.R.AND.TEST(3).LE.R) GO TO 20
      GO TO 21
   31 XA(K)=A(I)
      II=I
      GO TO 26
   19 IF(TEST(1).LE.R.AND.TEST(2).GE.R) GO TO 22
   27 IF(TEST(3).NE.R) GO TO 28
      XA(K)=A(3)
      II=3
      GO TO 26
   23 IF(TEST(2).NE.R) GO TO 24
   30 XA(K)=A(2)
      II=2
      GO TO 26
   28 IF(TEST(2).NE.R) GO TO 29
      GO TO 30
   29 A(1)=A(2)
      A(3)=A(3)
```

```
      A(2)=(A(2)+A(3))/2.
      GO TO 25
   24 A(1)=A(1)
      A(3)=A(2)
      A(2)=(A(1)+A(2))/2.
      GO TO 25
   20 IF(TEST(3).LE.R.AND.TEST(2).GE.R) GO TO 27
   22 IF(TEST(1).NE.R) GO TO 23
      XA(K)=A(1)
      II=1
      GO TO 26
   21 BAD=99999.
      WRITE(6,200) BAD,R,TEST(1),TEST(2),TEST(3)
      IF(TEST(1).GT.TEST(2).AND.TEST(2).GT.TEST(3)) GO TO 910
      IF(TEST(1).LT.TEST(2).AND.TEST(2).LT.TEST(3)) GO TO 911
      GO TO 5
  910 A(1)=A(1)+.1*FAC
      A(3)=A(2)
  912 A(2)=(A(1)+A(3))/2.
      GO TO 25
  911 A(1)=A(2)
      A(3)=A(3)-.1*FAC
      IF(A(3).LE.0.) GO TO 913
      GO TO 912
  914 FLG=1.
      WRITE(6,200) EX,EN,A(1),A(2),A(3),BAD
      GO TO 915
  913 WRITE(6,200) BAD
      STOP
   26 TT=0.
      EN=A(I)
      DO 201  JJ=1,IS
      L=J+1
  202 IF(D(J).GE.Z.AND.D(L).LE.Z) GO TO 203
  204 IF(G(J).EQ.999.) GO TO 205
  206 AA=((          GDV(J))+1.)*COS(EN)
  208 EX=ARCOS(AA)
      GO TO 209
  205 EX=EN
      DT=DR/V(J)/COS(EN)
      TT=TT+DT
      GO TO 210
  209 T1=(COS(EX)/(1.+SIN(EX)))*((1.+SIN(EN))/COS(EN))
      IF(T1.LT.0.) GO TO 914
      DT=( GIN(J))*ALOG(T1)
  211 TT=TT+DT
  210 EN=EX
  201 CONTINUE
```

```
216 EN=EX
    DT=DR/V(J)/COS(EN)
    TT=TT+DT
    GO TO 212
203 DM =D(J)-Z
    IF(G(J).EQ.999.) GO TO 216
    AA=((DM/DZ(J)*GDV(J))+1.)*COS(EN)
    EX=ARCOS(AA)
 14 T1=(COS(EX)/(1.+SIN(EX)))*((1.+SIN(EN))/COS(EN))
    IF(T1.LT.0.) GO TO 914
    DT=( GIN(J))*ALOG(T1)
    TT=TT+DT
212 TX(I)=TT
500 GG(K)  =TX(II)
    X1(K)=X/H(K)
    X2(K)=Y/H(K)
    T(K)=FLOAT(K-25)
    WRITE(6,200)  T(K),         GG(K),H(K),X1(K),X2(K),XA(K)
  5 CONTINUE
915 RETURN
    END
```

APPENDIX D

STUTRACK I

```
C     STUTRACK I(MOD 1)
C
C
C
C     THIS PROGRAM COMPUTES RANGE POSITION INFORMATION BY THE
C
C     ISOGRADIENT METHOD OF RAY-TRACING.
C
C
C     THE PROGRAM IS DESIGNED TO ACCEPT RANGE DATA, COMPUTE THE
C
C     APPARENT POSITION OF THE SOURCE IN THE SUBROUTINE ANGLE
C
C     AND RETURN TO THE MAIN PROGRAM TO COMPUTE THE X, Y, AND Z
C
C     POSITION OF THE ACOUSTIC SOURCE WITH RESPECT TO THE CENTER
C
C     OF THE RANGE ARRAY.  THE PROGRAM ALSO CONVERTS THE POSITION
C
C     INTO A SPHERICAL COORDINATE SYSTEM GIVING THE HORIZONTAL
C
C     ANGLE, THETA, THE VERTICAL ANGLE, PHI, AND THE RADIUS, R.
C
C
C     BEYOND THE INSTRUCTION 1, THE PROGRAM FITS THE DATA TO A
C
C     SECOND-ORDER CURVILINEAR REGRESSION FOR EACH COMPONENT
C
C     FOR EXPERIMENTAL ANALYSIS.  THE DIFFERENCE BETWEEN THE
C
C     REGRESSION EQUATION AND THE RESPECTIVE DATA IS TAKEN AND
C
C     VARIOUS STATISTICS ARE COMPUTED.
C
C     THE PROGRAM MAY BE USED TO SIMULATE THE APPARENT
C
C     POSITION OF THE SOURCE UNDER VARYING ENVIRONMENTAL
C
C     CONDITIONS USING SUBROUTINE ANGCAL ( APPENDIX C ).
C
C
C     INPUTS REQUIRED:
```

```
C
C        1. STATION NUMBER, NUMBER OF DEPTHS TO BE STUDIED,
C           NUMBER OF POINTS IN THE SVP, AND CLOCK HOUR DATA WAS
C           TAKEN(FORMAT - A2, 3I10).
C
C        2.  SOUND VELOCITY PROFILE - DEPTH-VELOCITY POINTS
C           (4 PER CARD) - (FORMAT - F10.1, F10.2)
C
C        3.  DATA
C           A.   DEPTH - (FORMAT - F5.0)
C           B.   TILT CORRECTION VALUES - TILTX, TILTY
C                (FORMAT - 2F10.0)
C           C.   CLOCK MINUTE(IHMIN), SECOND(ISEC), TRANSIT TIMES
C                TO  HYDROPHONES(TX, TY, TZ TC),AND RANGE COMPUTED
C                COMPONENTS(RBNX, RBNY, RBNZ)
C                (FORMAT - I4, I3, 1X, OF8.7, F7.6, 3F6.1)
C
C
C
      DIMENSION  RG(150), XG(150), YG(150), ZG(150)
      COMMON
     1/COM/ T(150),GG(150),XA(150),X1(150),X2(150),H(150)
      COMMON/COM2/DPH(100),V(100)
      COMMON/COM1/IM(150),IS(150),MM(7)
      COMMON/COM3/X(150),Y(150),Z(150)
      DIMENSION A(150),XM(5,7)
      DIMENSION   E(3,3), DX(7,150) , XC(3,150)
      DIMENSION XL(3,150),EE(8),AE(8),XI(3,150),DEP(7)
      DOUBLE PRECISION T,C,C1,C2,CP,XN,D,D0,D1,D2,E,B,B2,B3,B4
      DOUBLE PRECISION AA,DR
  101 FORMAT(4(F10.1,F10.2))
  102 FORMAT(5(5X,F5.1,5X,F7.2))
  700 FORMAT(F5.0)
  105 FORMAT(A2,3I10)
  300 FORMAT(6X,I4,'-',I2,5X,I4,6(4X,F7.1),3(4X,F5.1))
  500 FORMAT(6X, I4, '-', I2, 3(5X, F7.1), 2(5X, F6.2), 5X, F6.1,
     12(5X,F5.2),5X,F5.1)
 2000 FORMAT(1H1,4X,'STATION -',A3///,5X,'SOUND VELOCITY PROFILE'//,
     116X,5('SOUND', 17X)/,5(5X,'DEPTH',4X,'VELOCITY')/,5(5X,'(FT)',
     25X,'(FT/SEC)')/)
 2100 FORMAT(             36X,'CALCULATED',25X,'FITTED'  ,23X,'DIFFERENCE'
     1/,7X,'TIME',4X,'NORMALIZED',4X,'X',10X,'Y',10X,'Z',10X,'X',10X,
     2'Y',10X,'Z',9X,'DX',7X,'DY',7X,'DZ'/,5X,'(MIN-SEC)',4X,'(SEC)',5X,
     35('(FT)',7X) ,'(FT)',6X,3('(FT)',5X)/)
 5300 FORMAT(1H1,4X,'STATION -',A3//,5X,'DEPTH -',F4.0,' FT'//,
     15X,'NUMBER OF OBSERVATIONS -',I3//,5X,'TILTX - ',F4.0,3X,
     2'TILTY - ',F4.0////)
  665 FORMAT(1H1,4X,'STATION -',A3/)
```

```
 5400 FORMAT( 1X//,                        5X,'DEPTH -',F4.0,' FT'//,
     15X,'NUMBER OF OBSERVATIONS -',I3//,5X,'TILTX - ',F4.0,3X,
     2'TILTY - ',F4.0//)
 2400 FORMAT(      5X, 'SECCND ORDER EQUATIONS OF COMPONENTS AS FUNCTION
     1OF TIME'/,5X, '(TIME NORMALIZED TO MID-VALUE AT DEPTH)'///,
     2             5X,       'X = ', E12.5,' + ', E12.5, 'T + ', E12.5, 'T
     3 * T'//,  5X,    'Y = ', E12.5, ' + ', E12.5, 'T + ', E12.5, 'T * T
     4'//,5X,'Z = ',E12.5,'(AVERAGE)'//)
 2500 FORMAT(7X,'TIME',10X,
     1'X',11X,'Y',11X,'Z',8X,'THETA',7X,'PHI', 8X,'R',8X,'DTHETA',5X,
     2'DPHI',7X,'DR'/,5X,'(MIN-SEC)',
     36X,2('(FT)',8X),'(FT)',6X,'(DEG)',6X,'(DEG)',6X,'(FT)',
     47X,2('(DEG)',5X),'(FT)'/)
 5200 FORMAT(1X//   ,5X,'STATISTICS'//,20X,'DX',14X,'DY',14X,'DZ',
     110X,'DTHETA',10X,'DPHI',12X,'DR'/,
     25X,'MEAN',4X,6(3X,E12.5)/,5X,'VARIANCE',6(3X,E12.5)/,5X,
     3'STD DEV',1X,6(3X,E12.5)/,5X,'COEF OF'/,5X,'SKEWNESS',6(3X,E12.5)
     4/,5X,'CCEF OF'/,5X,'KURTOSIS',6(3X,E12.5)///)
 8000 FORMAT(1H1)
   38 FORMAT(2F10.0)
      FAC=57.29578
C
C     FLG INDICATES DESIRE TO SIMULATE OR CALCULATE
C
C     POSITION.  FLG=1. FOR SIMULATION.  FLG=0. OTHERWISE.
C
      TO=.00005
      INC=1
      N=150
      FLG=0.
      DO 20 IL=1,10
      READ(5,105) ISTA,IDEP,ISVP,IT
C
C  N  NUMBER OF INCREMENTS DESIRED IN SIMULATION
C
      IF(FLG.EQ.1..AND.IL.GT.1) GO TO 310
      READ(5,101)  (DPH(I), V(I), I=1,ISVP)
  310 KK=ISVP
      DO 20 ID=1,IDEP
      READ(5,700) DEPTH
      IF(FLG.EQ.1.) GO TO 320
      DEP(ID)= DEPTH
      READ(5,38) TILTX,TILTY
      GO TO 330
  320 CALL ANGCAL(KK,N)
      GO TO 340
  330 CALL ANGLE(TILTX,TILTY,KK,IT,N)
  340 RG(I)=0.
```

```
      TG=0.
      ZG(I)=0.
      IFLAG=0
C
C   THE ISOGRADIENT COMPUTATIONS BEGIN HERE
C
      DO 5 K=1,KK,INC
      IF(K.EQ.1) A(K)=XA(I)
      M=K+INC
      DZ=DPH(K)-DPH(M)
      IF(DZ.LT.1.) GO TO 5
      G=(V(M)-V(K))/DZ
      IF(G.EQ.0.) GO TO 201
   26 DZO=DZ/2.
   12 IF(G.EQ.0.) GO TO 201
      GT=ABS(G*DZ)
      IF(GT.LT..05) GO TO 27
      AA=(((G*DZ)*(1./V(K)))+1.) * COS(A(K))
      IF(AA.GT.1.) GO TO 49
      A(M)=DARCOS(AA)
      T1=( COS(A(M))/(1.+ SIN(A(M))))*((1.+ SIN(A(K)))/ COS(A(K)))
      DT=(1./G)*ALOG(T1)
  202 TG=TG+DT
   69 T2=GG(I)    -TG
      T3=ABS(T2)
      IF(T3.LE.TO)GO TO 50
      IF(T2)51,50,50
   27 G=0.
      GO TO 12
  201 A(M)=A(K)
      DR=DZ/TAN(A(K))
      DR=DSQRT(DR*DR)
      DT=DR/V(K)/COS(A(K))
      GO TO 202
   51 DZ=DZ-DZO
      TG=TG-DT
      DZO=DZO/2
      IFLAG=1
      GO TO 12
   50 IF(G.EQ.0.) GO TO 203
      DR=(-1.)*(V(K)/(G*COS(A(K))))*(SIN(A(M))-SIN(A(K)))
  203 RG(I)=RG(I)+DR
      ZG(I)=ZG(I)+DZ
      XL(3,N)=ZG(I)
      IF(T3.LE.TO)GO TO 52
      IF(IFLAG.NE.1)GO TO 5
   49 DZ=DZ-DZO
      DZO=DZO/2.
```

```
      GO TO 12
    5 CONTINUE
   52 XG(I)=(X(I)/H(I))*RG(I)
      YG(I)=(Y(I)/H(I))*RG(I)
      XL(1,N)=XG(I)
      XL(2,N)=YG(I)
    1 CONTINUE
C
C     STATISTICAL CALCULATIONS BEGIN HERE.
C
      B = 0.
      B2 =0.
      B4 = 0.
      B3 = 0.
      DO 62 K = 1,N
      B =  B + T(K)
      T2 = T(K) * T(K)
      B2 = B2 + T2
      B3 = B3 + T2* T(K)
   62 B4 = B4 + T2 * T2
      DO 63 I=1,2
      C = 0.
      C1 =0.
      C2 =0.
      DO 64 J = 1,N
      C=C+XL(I,J)
      CP=XL(I,J)*T(J)
      C1  = C1 + CP
      C2  = C2 + CP * T(J)
   64 CONTINUE
      XN = FLOAT(N)
      D = XN * B2 * B4 - B2 * B2 * B2
      D = B * B3 * B2  - XN * B3 * B3  + D
      D = B2 * B * B3 - B * B * B4 + D
      D0 = C * B2 * B4 - B2 * B2 * C2
      D0 = B * B3 * C2 - C  * B3 * B3 + D0
      D0 = B2 * C1 * B3 - B * C1 * B4  + D0
      D1 = XN * C1 * B4 - B2 * C1 * B2
      D1 = C * B3 * B2 - XN * B3 * C2  + D1
      D1 = B2 * B * C2 - C * B *  B4  + D1
      D2 = XN * B2 * C2 - C * B2 * B2
      D2 = B * C1 * B2 - XN * C1 * B3 + D2
      D2 = C * B * B3 - B * B * C2 + D2
      E(I,1)=D0/D
      E(I,2)=D1/D
      E(I,3)=D2/D
   63 CONTINUE
      XXX=0.
```

```
      DO 91  J=1,N
   91 XXX=XXX+XL(3,J)
      EE(3)=XXX/XN
      DO 92  J=1,3
   92 AE(J)=0.
      IF(FLG.EQ.1.) GO TO 93
      WRITE(6,5300) ISTA,DEPTH, N,TILTX,TILTY
      WRITE(6,2100)
   93 DO 66  J=1,N
      DO 67  II=1,2
      XI(II,J)=E(II,1)+E(II,2)*T(J)+E(II,3)*T(J)*T(J)
      DX(II,J)=XI(II,J)-XL(II,J)
      AE(II)=AE(II) +DX(II,J)
   67 CONTINUE
      XI(3,J)=EE(3  )
      DX(3,J)=XI(3,J)-XL(3,J)
      AE(3  )=AE(3  )+DX(3,J)
      TT=T(J)
      JSEC=IFIX(TT)
      IF(FLG.EQ.1.) GO TO 66
      IF(J.NE.63) GO TO 31
      WRITE(6,8000)
      WRITE(6,2100)
   31 WRITE(6,300)  IM(J),IS(J),JSEC,(XL(K,J),K=1,3),(XI(LL,J),LL=1,3),
     1(DX(L,J),L=1,3)
   66 CONTINUE
      IF(FLG.EQ.1.) GO TO 68
      WRITE(6,5300) ISTA,DEPTH, N,TILTX,TILTY
      WRITE(6,2500)
      DO 74  J=1,N
      XA1=XI(2,J)/XI(1,J)
      THETA=ATAN(XA1)*FAC
      RP=XI(1,J)*XI(1,J)+XI(2,J)*XI(2,J)+XI(3,J)*XI(3,J)
      XA2=XI(3,J)/SQRT(RP)
      PHI=ARSIN(XA2)*FAC
      R=SQRT(RP)
      DTHETA=THETA-XC(1,J)
      DPHI=PHI-XC(2,J)
      DR=R-XC(3,J)
      DX(4,J)=DTHETA
      DX(5,J)=DPHI
      DX(6,J)=DR
      AE(4)=AE(4)+DTHETA
      AE(5)=AE(5)+DPHI
      AE(6)=AE(6)+DR
      IF(FLG.EQ.1.) GO TO 74
      IF(J.NE.63) GO TO 32
      WRITE(6,8000)
```

```
      WRITE(6,2500)
   32 WRITE(6,500) IM(J),IS(J),(XL(K,J),K=1,3), THETA,PHI,R,
     1DTHETA,DPHI,DR
   74 CONTINUE
      DO 75 I=1,6
   75 AE(I)=AE(I)/XN
      DO 71 I=1,6
      DO 73 J=1,5
      XM(J,I)=0.
   73 CONTINUE
      DO 72 J=1,N
      DIFF=DX(I,J)-AE(I)
      DIFF2=DIFF*DIFF
      XM(2,I)=XM(2,I)+DIFF2
      XM(4,I)=XM(4,I)+DIFF*DIFF2
      XM(5,I)=XM(5,I)+DIFF2*DIFF2
   72 CONTINUE
      XM(1,I)=AE(I)
      XM(2,I)=XM(2,I)/XN
      IF(FLG.EQ.1.) GO TO 76
      GO TO 78
   76 STDER=XM(2,I)*XN/(XN-3.)
      STDER=SQRT(STDER)
      WRITE(6,77) I,STDER
   77 FORMAT(5X,I3,5X,E12.5)
   78 XM(4,I)=XM(4,I)/XN
      XM(5,I)=XM(5,I)/XN
      XM(3,I)=SQRT(XM(2,I))
   71 CONTINUE
      IF(ID-2) 33,34,34
   33 WRITE(6,2000) ISTA
      WRITE(6,102) (DPH(I),V(I), I=1,ISVP)
      GO TO 37
   34 WRITE(6,665 ) ISTA
   37 WRITE(6,5400)       DEPTH, N,TILTX,TILTY
      WRITE(6,2400) ((E(I,J), J=1,3), I= 1,2),AE(3)
      WRITE(6,5200)  ((XM(J,I),I=1,6),J=1,5)
   20 CONTINUE
      WRITE(6,8000)
  999 STOP
      END
```

SUBROUTINE ANGLE

```
C
C     SUBROUTINE ANGLE
C
C
C     THIS SUBROUTINE COMPUTES THE APPARENT POSITION OF A
C
C     SOURCE FROM THE CENTER OF THE ARRAY AND THE TRANSIT
C
C     TIME OF AN ACOUSTIC PULSE BETWEEN THESE TWO POINTS.
C
C     THE RESULTS ARE USED AS INPUTS TO STUTRACK I.
C
C
      SUBROUTINE ANGLE(TILTX,TILTY,KK,IT,M)
      COMMON
     1/COM/ T(150),GG(150),XA(150),X1(150),X2(150),H(150)
      COMMON/COM3/X(150),Y(150),Z(150)
      COMMON/COM1/IM(150),IS(150),MM(6)
      COMMON/COM2/  D(100),V(100)
      DIMENSION A(2),TR(150)
  103 VO=4860.
      N=0
      DO 1 I=1,M
      READ(5,2)IHMIN,ISEC,TX,TY,TZ,TC,RBNX,RBNY,RBNZ
    2 FORMAT(I4,I3,1X,3F8.7,F7.6,3F6.1)
      JSEC=(IHMIN-IT)*60+ISEC
      IFLAG=0
      IF(IHMIN.EQ.9999)GO TO 19
      N=N+1
      IF(JSEC.GE.6000) JSEC=(IHMIN-IT-40)*60+ISEC
      TR(N)= FLOAT(JSEC)
      IM(N)= IHMIN
      IS(N)= ISEC
      X(I)=((VO*VO)/60.)*(TC+TX-.0016)*(TC-TX)
      Y(I)=((VO*VO)/60.)*(TC+TY-.0016)*(TC-TY)
      Z(I)=((VO*VO)/60.)*(TC+TZ-.0016)*(TC-TZ)
      XO=X(I)
      YO=Y(I)
      XTILT=(TILTX-505.)*(.000145386)
      YTILT=(TILTY-505.)*(.000145386)
      X(I)=X(I)-(Z(I)*SIN(XTILT))
      Y(I)=Y(I)-(Z(I)*SIN(YTILT))
      X1(I)=X(I)
      X2(I)=Y(I)
```

```
      Z(I)=Z(I)+(XO*SIN(XTILT))+(YO*SIN(YTILT))
      S=(((X(I)*X(I))+(Y(I)*Y(I))+(Z(I)*Z(I)))**.5)
      AA=Z(I)/S
      A(1)= ARSIN(AA)
      XA(I)=A(1)
      H( I)=S*COS(XA(I))
      GG(I)=(TC*S)/RC
    1 CONTINUE
      NP=N/2
      DO 3 I=1,N
      T(I)=TR(I)-TR(NP)
    3 CONTINUE
   19 RETURN
      END
```

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